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PHYSICS

Based on the Revised CBSE Syllabus

Competency-Focused Questions

CBSE Examination Papers-2023

Constructed Response Questions

CBSE Sample Question Paper-2024

NCERT Textbook & Exemplar Questions

XII

2023-24

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Syllabus

CENTRAL BOARD OF SECONDARY EDUCATION, NEW DELHI

PHYSICS (Code No. 042)

CLASS–XII (2023-24)

Time allowed: 3 hours **Maximum marks: 70**

Units		No. of Periods	Marks
I	**Electrostatics** 1. Electric Charges and Fields 2. Electrostatic Potential and Capacitance	26	16
II	**Current Electricity** 3. Current Electricity	18	
III	**Magnetic Effects of Current and Magnetism** 4. Moving Charges and Magnetism 5. Magnetism and Matter	25	17
IV	**Electromagnetic Induction and Alternating Currents** 6. Electromagnetic Induction 7. Alternating Current	24	
V	**Electromagnetic Waves** 8. Electromagnetic Waves	04	18
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VII	**Dual Nature of Radiation and Matter** 11. Dual Nature of Radiation and Matter	08	12
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IX	**Electronic Devices** 14. Semiconductor Electronics: Materials, Devices and Simple Circuits	10	7
	Total	**160**	**70**

Unit I: Electrostatics (26 Periods)

Chapter 1: Electric Charges and Fields

Electric charges, Conservation of charge, Coulomb's law: force between two-point charges, forces between multiple charges; superposition principle and continuous charge distribution.

Electric field, electric field due to a point charge, electric field lines, electric dipole, electric field due to a dipole, torque on a dipole in uniform electric field.

Electric flux, statement of Gauss's theorem and its applications to find field due to infinitely long straight wire, uniformly charged infinite plane sheet and uniformly charged thin spherical shell (field inside and outside).

Chapter 2: Electrostatic Potential and Capacitance

Electric potential, potential difference, electric potential due to a point charge, a dipole and system of charges; equipotential surfaces, electrical potential energy of a system of two-point charges and of electric dipole in an electrostatic field.

Conductors and insulators, free charges and bound charges inside a conductor. Dielectrics and electric polarization, capacitors and capacitance, combination of capacitors in series and in parallel, capacitance of a parallel plate capacitor with and without dielectric medium between the plates, energy stored in a capacitor (no derivation, formulae only).

Unit II: Current Electricity (18 Periods)

Chapter 3: Current Electricity

Electric current, flow of electric charges in a metallic conductor, drift velocity, mobility and their relation with electric current; Ohm's law, V-I characteristics (linear and non-linear), electrical energy and power, electrical resistivity and conductivity, temperature dependence of resistance, Internal resistance of a cell, potential difference and emf of a cell, combination of cells in series and in parallel, Kirchhoff's rules, Wheatstone bridge.

Unit III: Magnetic Effects of Current and Magnetism (25 Periods)

Chapter 4: Moving Charges and Magnetism

Concept of magnetic field, Oersted's experiment.

Biot - Savart law and its application to current carrying circular loop.

Ampere's law and its applications to infinitely long straight wire. Straight solenoid (only qualitative treatment), force on a moving charge in uniform magnetic and electric fields.

Force on a current-carrying conductor in a uniform magnetic field, force between two parallel current-carrying conductors-definition of ampere, torque experienced by a current loop in uniform magnetic field; Current loop as a magnetic dipole and its magnetic dipole moment, moving coil galvanometer-its current sensitivity and conversion to ammeter and voltmeter.

Chapter 5 : Magnetism and Matter

Bar magnet, bar magnet as an equivalent solenoid (qualitative treatment only), magnetic field intensity due to a magnetic dipole (bar magnet) along its axis and perpendicular to its axis (qualitative treatment only), torque on a magnetic dipole (bar magnet) in a uniform magnetic field (qualitative treatment only), magnetic field lines.

Magnetic properties of materials- Para-, dia- and ferro - magnetic substances with examples, Magnetization of materials, effect of temperature on magnetic properties.

Unit IV: Electromagnetic Induction and Alternating Currents (24 Periods)

Chapter 6: Electromagnetic Induction

Electromagnetic induction; Faraday's laws, induced EMF and current; Lenz's Law, Self and mutual induction.

Chapter 7: Alternating Current

Alternating currents, peak and RMS value of alternating current/voltage; reactance and impedance; LCR series circuit (phasors only), resonance, power in AC circuits, power factor, wattless current.

AC generator, Transformer.

Unit V: Electromagnetic Waves (04 Periods)

Chapter 8: Electromagnetic Waves

Basic idea of displacement current, Electromagnetic waves, their characteristics, their transverse nature (qualitative idea only).

Electromagnetic spectrum (radio waves, microwaves, infrared, visible, ultraviolet, X-rays, gamma rays) including elementary facts about their uses.

Unit VI: Optics (30 Periods)

Chapter 9: Ray Optics and Optical Instruments

Ray Optics: Reflection of light, spherical mirrors, mirror formula, refraction of light, total internal reflection and optical fibers, refraction at spherical surfaces, lenses, thin lens formula, lens maker's formula, magnification, power of a lens, combination of thin lenses in contact, refraction of light through a prism.

Optical instruments: Microscopes and astronomical telescopes (reflecting and refracting) and their magnifying powers.

Chapter 10: Wave Optics

Wave Optics: Wave front and Huygen's principle, reflection and refraction of plane wave at a plane surface using wave fronts. Proof of laws of reflection and refraction using Huygen's principle. Interference, Young's double slit experiment and expression for fringe width (No derivation final expression only), coherent sources and sustained interference of light, diffraction due to a single slit, width of central maxima (qualitative treatment only).

Unit VII: Dual Nature of Radiation and Matter (08 Periods)

Chapter 11: Dual Nature of Radiation and Matter

Dual nature of radiation, Photoelectric effect, Hertz and Lenard's observations; Einstein's photoelectric equation-particle nature of light.

Experimental study of photoelectric effect

Matter waves-wave nature of particles, de Broglie relation.

Unit VIII: Atoms and Nuclei (15 Periods)

Chapter 12: Atoms

Alpha-particle scattering experiment; Rutherford's model of atom; Bohr model of hydrogen atom, Expression for radius of nth possible orbit, velocity and energy of electron in nth orbit, hydrogen line spectra (qualitative treatment only).

Chapter 13: Nuclei

Composition and size of nucleus, nuclear force

Mass-energy relation, mass defect; binding energy per nucleon and its variation with mass number; nuclear fission, nuclear fusion.

Unit IX: Electronic Devices (10 Periods)

Chapter 14: Semiconductor Electronics: Materials, Devices and Simple Circuits

Energy bands in conductors, semiconductors and insulators (qualitative ideas only) Intrinsic and extrinsic semiconductors- p and n type, p-n junction

Semiconductor diode: I-V characteristics in forward and reverse bias, application of junction diode – diode as a rectifier.

Design of Question Paper

PHYSICS (Theory)-XII

Time allowed: 3 hours			Maximum marks: 70
S. No.	**Typology of Questions**	**Total Marks**	**Approximate Percentage**
1.	**Remembering:** Exhibit memory of previously learned material by recalling facts, terms, basic concepts, and answers. **Understanding:** Demonstrate understanding of facts and ideas by organizing, comparing, translating, interpreting, giving descriptions, and stating main ideas	27	38%
2.	**Applying:** Solve problems to new situations by applying acquired knowledge, facts, techniques and rules in a different way.	22	32%
3.	**Analysing:** Examine and break information into parts by identifying motives or causes. Make inferences and find evidence to support generalizations **Evaluating:** Present and defend opinions by making judgments about information, validity of ideas, or quality of work based on a set of criteria. **Creating:** Compile information together in a different way by combining elements in a new pattern or proposing alternative solutions.	21	30%
	Total	**70**	**100%**
	Practical	**30**	
	Gross Total	**100**	

Note: The above template is only a sample. Suitable internal variations may be made for generating similar templates keeping the overall weightage to different form of questions and typology of questions same.

The changes for class XII (2023-24) Board Examination are as under:		
Particulars	**Academic Session 2022-23**	**Academic Session 2023-24**
Composition of question paper for Board Examination (Theory)	❖ Competency Based Questions are 30% in the form of Multiple-Choice Questions, Case Based Questions, Source Based Integrated Questions or any other type. ❖ Objective Questions are 20% ❖ Remaining 50% Questions are Short Answer/Long Answer Questions	❖ Competency Focused Questions in the form of MCQs/Case Based Questions, Source-based Integrated Questions or any other type = 40% ❖ Select response type questions (MCQ) = 20% ❖ Constructed response questions (Short Answer Questions/Long Answer type Questions, as per existing pattern) = 40%

PART–A

- Points to Remember
- Competency-Focused Questions (As Per NEP)
  - Multiple Choice Questions
  - Assertion-Reason Questions
  - Case-based/Passage-based Questions
- Conceptual Questions
- Constructed Response Questions (As Per NEP)
  - Very Short Answer Questions
  - Short Answer Questions
  - Long Answer Questions
- Questions For Practice

1 Electric Charges and Fields

POINTS TO REMEMBER

The study of electric charges at rest is called Electrostatics.

1. Two Kinds of Electric Charges

When two bodies are rubbed together, they get oppositely charged. Experimental evidences show that there are two types of charges:

(*i*) **Positive Charge:** Positive charge is produced by the removal of electrons from a neutral body. That is, positive charge means deficiency of electrons.

(*ii*) **Negative Charge:** Negative charge is produced by giving electrons to a neutral body. That is, negative charge means excess of electrons on a neutral body.

SI unit of charge is coulomb (C).

2. Properties of Charges

(*i*) **Conservation of Charge:** The charge of an isolated system remains constant. This means that charge can neither be created nor destroyed, but it may simply be transferred from one body to another.

(*ii*) **Additive Property:** Total charge on an isolated system is equal to the algebraic sum of charges on individual bodies of the system. This is called additive property of charges. That is, if a system contains three charges, $q_1, q_2, -q_3$, then total charge on system, $Q = q_1 + q_2 - q_3$.

(*iii*) **Quantisation of Charge:** The total charge on a body is the integral multiple of fundamental charge 'e'

i.e., $q = \pm ne$ where n is an integer ($n = 1, 2, 3, ...$).

(*iv*) **Charge is unaffected by motion:** The charge on a body remains unaffected of its velocity, *i.e.*,

Charge at rest = Charge in motion

(*v*) **Like charges repel while unlike charges attract each other.**

3. Coulomb's Law in General Form

It states that the force of attraction or repulsion between two point charges is directly proportional to the product of magnitude of charges and inversely proportional to the square of distance between them. The direction of this force is along the line joining the two charges, i.e.,

$$F = k\frac{q_1 q_2}{r^2}$$

where $k = \dfrac{1}{4\pi\varepsilon}$ is constant of proportionality; ε is permittivity of medium between the charges. If ε_0 is permittivity of free space and K the dielectric constant of medium, then $\varepsilon = K\varepsilon_0$

$$F = \frac{1}{4\pi\varepsilon_0 K}\frac{q_1 q_2}{r^2}$$

For free space $K = 1$, Therefore

$$\therefore \qquad F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

Dielectric constant or Relative permittivity (K): The dielectric constant of a medium is defined as the ratio of permittivity of medium to the permittivity of free space, *i.e.*, $K = \varepsilon/\varepsilon_0$

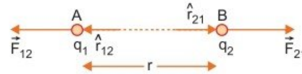
Definition of coulomb: 1 coulomb charge is the charge which when placed at a distance of 1 metre from an equal and similar charge in vacuum (or air) will repel it with a force of 9×10^9 N.

4. Coulomb's Law in Vector Form

Consider two like charges q_1 and q_2 located at points A and B in vacuum. The separation between the charges is r. As charges are like, they repel each other. Let $\vec{F}_{21}$ be the force exerted on charge q_2 by charge q_1 and $\vec{F}_{12}$ that exerted on charge q_1 by charge q_2. If $\vec{r}_{21}$ is the position vector of q_2 relative to q_1 and $\hat{r}_{21}$ is unit vector along A to B, then the force $\vec{F}_{21}$ is along A to B and

$$\vec{F}_{21} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}\hat{r}_{21} \qquad ...(i)$$

But $\qquad \hat{r}_{21} = \dfrac{\vec{r}_{21}}{r}$



$$\vec{F}_{21} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}\frac{\vec{r}_{21}}{r} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^3}\vec{r}_{21}$$

Similarly if $\vec{r}_{12}$ is position vector of q_1 relative to q_2 and $\hat{r}_{12}$ is unit vector from B to A, then

$$\vec{F}_{12} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}\hat{r}_{12} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^3}\vec{r}_{12} \qquad ...(ii)$$

Obviously $\vec{r}_{12} = -\vec{r}_{21}$, therefore equation (*ii*) becomes

$$\therefore \qquad \vec{F}_{12} = -\frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^3}\vec{r}_{21} \qquad ...(iii)$$

Comparing (*i*) and (*iii*), we get

$$\vec{F}_{21} = -\vec{F}_{12}$$

This means that the Coulomb's force exerted on q_2 by q_1 is equal and opposite to the Coulomb's force exerted on q_1 by q_2; in accordance with Newton's third law.

Thus, Newton's third law also holds good for electrical forces.

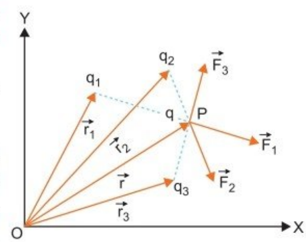
5. Principle of Superposition of Electric Charges

Coulomb's law gives the force between two point charges. But if there are a number of interacting charges, then the force on a particular charge may be found by the principle of superposition. It states that

If the system contains a number of interacting charges, then the force on a given charge is equal to the vector sum of the forces exerted on it by all remaining charges.

The force between any two charges is not affected by the presence of other charges.

Suppose that a system of charges contains n charges $q_1, q_2, q_3, \ldots q_n$ having position vectors $\vec{r}_1, \vec{r}_2, \vec{r}_3, \ldots \vec{r}_n$ relative to origin O respectively. A point charge q is located at P having position vector $\vec{r}$ relative to O. The total force on q due to all n charges



is to be found. If $\vec{F}_1, \vec{F}_2, \vec{F}_3, \ldots \vec{F}_n$, are the forces acting on q due to charges $q_1, q_2, q_3, \ldots q_n$ respectively, then by the principle of superposition, the net force on q is

$$\vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots + \vec{F}_n$$

If the force exerted due to charge q_i on q is $\vec{F}_i$, then from Coulomb's law in vector form

$$\vec{F}_i = \frac{1}{4\pi\varepsilon_0}\frac{qq_i}{|\vec{r} - \vec{r}_i|^3}(\vec{r} - \vec{r}_i)$$

The total force on q due to all n charges may be expressed as

$$\vec{F} = \sum_{i=1}^{n} \vec{F}_i = \sum_{i=1}^{n} \frac{1}{4\pi\varepsilon_0}\frac{qq_i}{|\vec{r} - \vec{r}_i|^3}(\vec{r} - \vec{r}_i)$$

$$= \frac{1}{4\pi\varepsilon_0} q \sum_{i=1}^{n} \frac{q_i}{|\vec{r} - \vec{r}_i|^3}(\vec{r} - \vec{r}_i)$$

Here Σ represents the vector-sum.

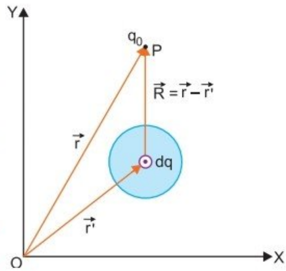
6. Continuous Charge Distribution

The electrostatic force due to a charge element dq at charge q_0 situated at point P is

$$d\vec{F} = \frac{1}{4\pi\varepsilon_0}\frac{q_0 dq}{R^3}\vec{R} = \frac{1}{4\pi\varepsilon_0}\frac{q_0 dq}{|\vec{r} - \vec{r}'|^3}(\vec{r} - \vec{r}')$$

The total force on q_0 by the charged body is

$$F = \frac{1}{4\pi\varepsilon_0} q_0 \int \frac{dq(\vec{r} - \vec{r}')}{|\vec{r} - \vec{r}'|^3}$$



For **linear charge distribution,** $dq = \lambda\, dl$, where λ is charge per unit length and integration is over the whole length of charge.

For **surface charge distribution,** $dq = \sigma\, dS$, where σ is charge per unit area and integration is for the whole surface of charge.

For **volume charge distribution,** $dq = \rho\, dV$, where ρ is charge per unit volume and integration is for whole volume of charge.

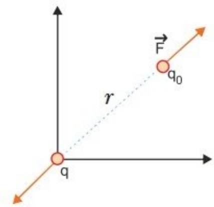
Electric field

The electric field strength at any point in an electric field is a vector quantity whose magnitude is equal to the force acting on a unit positive test charge and the direction is along the direction of force.

If $\vec{F}$ is the force acting on infinitesimal positive test charge q_0, then electric field strength, $\vec{E} = \frac{\vec{F}}{q_0}$.

Therefore from definition, electric field can be given as

$$\vec{E} = \lim_{q_0 \to 0} \frac{\vec{F}}{q_0}$$



The unit of electric field strength is newton/coulomb or volt/metre (abbreviated as N/C or V/m respectively).

(*i*) The electric field strength due to a point charge q at a distance r in magnitude form

$$|\vec{E}| = \frac{|\vec{F}|}{q_0} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$

In vector form, $\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^3}\vec{r}$

(*ii*) The electric field strength due to a system of discrete charge is

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n}\frac{q_i}{r_i^3}\vec{r}_i$$

(*iii*) The electric field strength due to a continuous charge distribution is

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\int\frac{dq}{r^3}\vec{r}$$

7. Electric field lines

An electric field line is a curve drawn in such a way that tangent to it at each point is in the direction of the net field at that point.

Properties of electric field lines

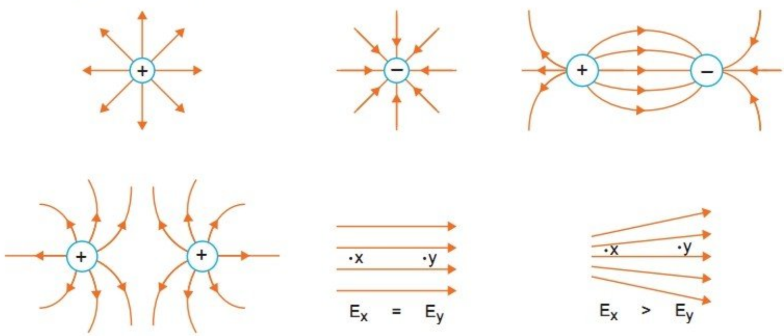
(*i*) Field lines start from positive charges and end at negative charges. If there is a single charge, they may start or end at infinity.

(*ii*) In a charge-free region, electric field lines can be taken to be continuous curves without any breaks.

(*iii*) No two electric field lines can intersect each other because if they do so, then two tangents can be drawn at the point of intersection; which would mean two directions of electric field strength at one point and that is impossible.

(*iv*) The electric field lines do not form any closed loops. This follows from the conservative nature of electric field.

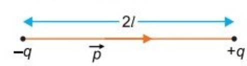
(*v*) The equidistant electric field lines represent uniform electric field while electric field lines at different separations represent non-uniform electric field (Figure).



8. Electric Dipole

A system containing two equal and opposite charges separated by a finite distance is called an *electric dipole*. Dipole moment of electric dipole having charges $+q$ and $-q$ at separation $2l$ is defined as the product of magnitude of one of the charges and shortest distance between them.

$$\vec{p} = q2\vec{l}$$



It is a vector quantity, directed from $-q$ to $+q$

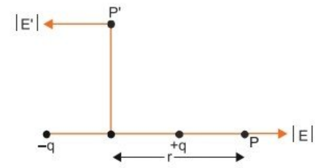
[**Remark:** Net charge on an electric dipole is zero.]

9. Electric Field Due to a Short Dipole

(*i*) At a point P on axis, $E = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3}$

(*ii*) At a point P' on equatorial line,

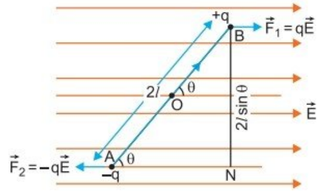
$$E' = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}$$



10. Electric Force and Torque on an Electric Dipole in a Uniform Electric Field

In a uniform electric field of strength E, the net electric force is zero; but a torque equal to $pE \sin\theta$ acts on the dipole (where θ is the angle between directions of dipole moment $\vec{p}$ and electric field $\vec{E}$). This torque tends to align the dipole along the direction of electric field.

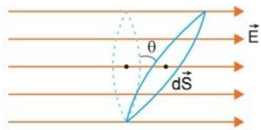
Torque in vector form $\vec{\tau} = \vec{p} \times \vec{E}$.



11. Electric Flux

The total number of electric field lines crossing (or diverging) a surface normally is called electric flux.

Electric flux through surface element $d\vec{S}$ is $\Delta\phi = \vec{E}.d\vec{S} = E\, dS \cos\theta$, where $\vec{E}$ is electric field strength.



Electric flux through entire closed surface is

$$\phi = \oint_S \vec{E}\,.\,d\vec{S}$$

SI unit of electric flux is volt-metre or Nm^2C^{-1}.

12. Gauss's Theorem

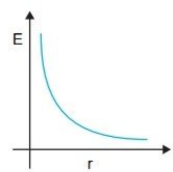
It states that the total electric flux through a closed surface is equal to $\frac{1}{\varepsilon_0}$ times the net charge enclosed by the surface

i.e.,
$$\phi = \int_S \vec{E}\,.\,d\vec{S} = \frac{1}{\varepsilon_0}\Sigma q$$

13. Formulae for Electric Field Strength Calculated from Gauss's Theorem

(*a*) **Electric field due to infinitely long straight wire of charge** per unit length λ at a distance r from the wire is

$$E = \frac{1}{4\pi\varepsilon_0}\frac{2\lambda}{r}$$



(*b*) **Electric field strength due to an infinite plane sheet of charge per unit area** σ is

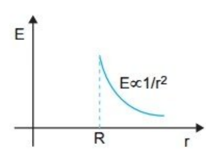
$$E = \frac{\sigma}{2\varepsilon_0}, \text{ independent of distance of point from the sheet.}$$

(*c*) **Electric field strength due to a uniformly charged thin spherical shell** or conducting sphere of radius R having total charge q, at a distance r from centre is

(*i*) at external point $E_{ext} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$ (For $r > R$)

(*ii*) at surface point $E_S = \frac{1}{4\pi\varepsilon_0}\frac{q}{R^2}$ (For $r = R$)

(*iii*) at internal point $E_{int} = 0$ (For $r < R$)

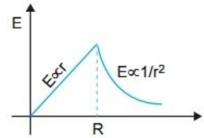


(*d*) **Electric field strength due to a uniformly charged non-conducting solid sphere of radius R at a distance r from centre**

(*i*) at external point $E_{ext} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{r^2}$ (For $r > R$)

(*ii*) at surface point $E_S = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{R^2}$ (For $r = R$)

(*iii*) at internal point, $E_{int} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{qr}{R^3}$ (For $r < R$)



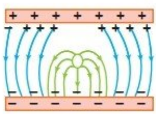
COMPETENCY-FOCUSED QUESTIONS AS PER NEP

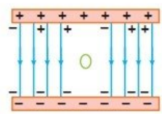
Multiple Choice Questions

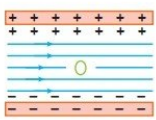
Choose and write the correct option(s) in the following questions.

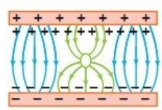
1. **Which statement is true for Gauss law?** *[CBSE Sample Paper-2022, Term-1)]*
   (*a*) All the charges whether inside or outside the Gaussian surface contribute to the electric flux.
   (*b*) Electric flux depends upon the geometry of the Gaussian surface.
   (*c*) Gauss theorem can be applied to non-uniform electric field.
   (*d*) The electric field over the Gaussian surface remains continuous and uniform at every point.

2. **Which of the diagrams correctly represents the electric field between two charged plates if a neutral conductor is placed in between the plates?** *[CBSE 2022, (55/2/4), Term-1]*

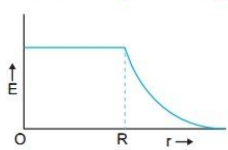
   (*a*)
   

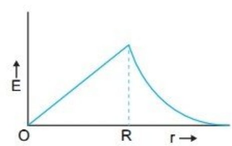
   (*b*)
   

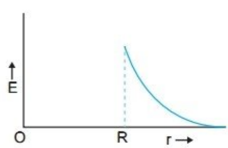
   (*c*)
   

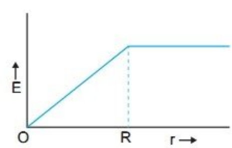
   (*d*)
   

3. **The electric field due to a uniformly charged sphere of radius R as a function of the distance from its centre is represented graphically by**

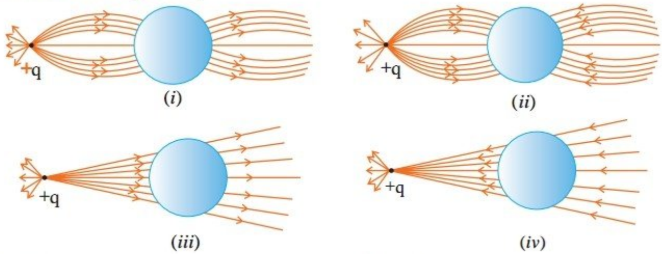
   (*a*)
   

   (*b*)
   

   (*c*)
   

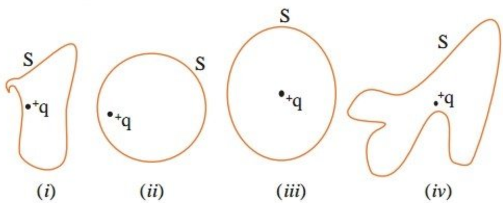
   (*d*)
   

4. **A point positive charge is brought near an isolated conducting sphere (Fig. given below). The electric field is best given by** [*NCERT Exemplar*]



(*a*) Fig (*i*)
(*b*) Fig (*ii*)
(*c*) Fig (*iii*)
(*d*) Fig (*iv*)

5. **The Electric flux through the surface** [*NCERT Exemplar*]

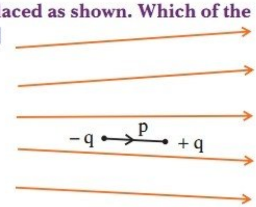


(*a*) in Fig. (*iv*) is the largest.
(*b*) in Fig. (*iii*) is the least.
(*c*) in Fig. (*ii*) is same as Fig. (*iii*) but is smaller than Fig. (*iv*)
(*d*) is the same for all the figures.

6. **A hemisphere is uniformly charged positively. The electric field at a point on a diameter away from the centre is directed** [*NCERT Exemplar*]
(*a*) perpendicular to the diameter
(*b*) parallel to the diameter
(*c*) at an angle tilted towards the diameter
(*d*) at an angle tilted away from the diameter

7. **An electric dipole placed in a non-uniform electric field can experience** [*CBSE 2020 (55/1/2)*]
(*a*) a force but not a torque.
(*b*) a torque but not a force.
(*c*) always a force and a torque.
(*d*) neither a force nor a torque.

8. **Figure shows electric field lines in which an electric dipole *p* is placed as shown. Which of the following statements is correct?** [*NCERT Exemplar*]



(*a*) the dipole will not experience any force.
(*b*) the dipole will experience a force towards right.
(*c*) the dipole will experience a force towards left.
(*d*) the dipole will experience a force upwards.

9. **A point charge $+q$, is placed at a distance d from an isolated conducting plane. The field at a point P on the other side of the plane is** [*NCERT Exemplar*]
(*a*) directed perpendicular to the plane and away from the plane.
(*b*) directed perpendicular to the plane but towards the plane.
(*c*) directed radially away from the point charge.
(*d*) directed radially towards the point charge.

10. **If $\oint \vec{E}.d\vec{S} = 0$ over a surface, then** [*NCERT Exemplar*]

(*a*) the electric field inside the surface and on it is zero.

(*b*) the electric field inside the surface is necessarily uniform.

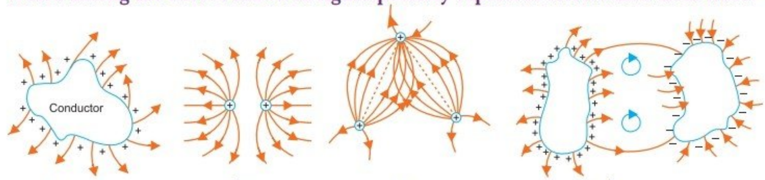
(*c*) the number of flux lines entering the surface must be equal to the number of flux lines leaving it.

(*d*) all charges must necessarily be outside the surface.

11. **Two charges are at distance d apart in air. Coulomb force between them is F. If a dielectric material of dielectric constant K is placed between them, the Coulomb force now becomes**

(*a*) F/K (*b*) FK (*c*) F/K^2 (*d*) K^2F

12. **Which among the curves shown in figure possibly represent electrostatic field lines?**



(*a*) (*b*) (*c*) (*d*)

13. **Two point charges A and B, having charges $+q$ and $-q$ respectively, are placed at certain distance apart and force acting between them is F. If 25% charge of A is transferred to B, then force between the charges becomes**

(*a*) F (*b*) $\frac{9F}{16}$ (*c*) $\frac{16F}{3}$ (*d*) $\frac{4F}{3}$

14. **Two large conducting spheres carrying charges Q_1 and Q_2 are kept with their centres r distance apart. The magnitude of electrostatic force between them is not exactly $\frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$ because** [*CBSE 2020 (55/3/3)*]

(*a*) these are not point charges.

(*b*) charge distribution on the spheres is not uniform.

(*c*) charges on spheres will shift towards the centres of their respective spheres.

(*d*) charges will shift towards the portions of the spheres which are closer and facing towards each other.

15. **A negatively charged object X is repelled by another charged object Y. However an object Z is attracted to object Y. Which of the following is the most possibility for the object Z?** [*CBSE 2022 (55/2/4), Term-1*]

(*a*) positively charged only (*b*) negatively charged only

(*c*) neutral or positively charged (*d*) neutral or negatively charged

16. **In an experiment three microscopic latex spheres are sprayed into a chamber and became charged with charges +3e, +5e, and – 3e respectively. All the three spheres came in contact simultaneously for a moment and got separated. Which one of the following are possible values for the final charge on the spheres?** [*CBSE 2022 (55/2/4), Term-1*]

(*a*) $+5e, -4e, +5e$ (*b*) $+6e, +6e, -7e$

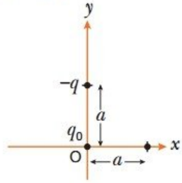
(*c*) $-4e, +3.5e, +5.5e$ (*d*) $+5e, -8e, +7e$

17. **The magnitude of electric field due to a point charge $2q$, at distance r is E. Then the magnitude of electric field due to a uniformly charged thin spherical shell of radius R with total charge q at a distance $\frac{r}{2}(r >> R)$ will be** [*CBSE 2022 (55/2/4), Term-1*]

(*a*) $\frac{E}{4}$ (*b*) 0

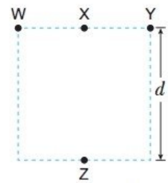
(*c*) $2E$ (*d*) $4E$

18. **Three charges q, $-q$ and q_0 are placed as shown in figure. The magnitude of the net force on the charge q_0 at point O is $\left[k = \frac{1}{(4\pi\varepsilon_0)}\right]$** [*CBSE 2022 (55/2/4), Term-1*]



(*a*) 0 (*b*) $\frac{2kqq_0}{a^2}$ (*c*) $\frac{\sqrt{2}\,kqq_0}{a^2}$ (*d*) $\frac{1}{\sqrt{2}}\frac{kqq_0}{a^2}$

19. **Four objects W, X, Y and Z, each with charge $+q$ are held fixed at four points of a square of side d as shown in the figure. Objects X and Z are on the midpoints of the sides of the square. The electrostatic force exerted by object W on object X is F. Then the magnitude of the force exerted by object W on Z is** [*CBSE 2022 (55/2/4), Term-1*]



(*a*) $\frac{F}{7}$ (*b*) $\frac{F}{5}$ (*c*) $\frac{F}{3}$ (*d*) $\frac{F}{2}$

20. **A square sheet of side 'a' is lying parallel to XY plane at $z = a$. The electric field in the region is $\vec{E} = cz^2\hat{k}$. The electric flux through the sheet is** [*CBSE 2022 (55/2/4), Term-1*]

(*a*) a^4c (*b*) $\frac{1}{3}a^3c$ (*c*) $\frac{1}{3}a^4c$ (*d*) 0

21. **Two point charges placed in a medium of dielectric constant 5 are at a distance r between them, experience an electrostatic force 'F'. The electrostatic force between them in vacuum at the same distance r will be** [*CBSE Sample Paper-2022, Term-1*]

(*a*) $5F$ (*b*) F (*c*) $F/2$ (*d*) $F/5$

22. **Consider an uncharged conducting sphere. A positive point charge is placed outside the sphere. The net charge on the sphere is then,** [*CBSE Sample Paper-2022, Term-1*]

(*a*) negative and uniformly distributed over the surface of sphere
(*b*) positive and uniformly distributed over the surface of sphere
(*c*) negative and appears at a point on the surface of sphere closest to point charge
(*d*) zero

23. **A cylinder of radius r and length l is placed in a uniform electric field parallel to the axis of the cylinder. The total flux for the surface of the cylinder is given by**

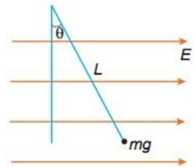
[*CBSE Sample Paper-2022, Term-1*]

(*a*) zero (*b*) πr^2
(*c*) $E\pi r^2$ (*d*) $2\,E\pi r^2$

24. **Two parallel large thin metal sheets have equal surface densities 26.4×10^{-12} C/m^2 of opposite signs. The electric field between these sheets is** [*CBSE Sample Paper-2022, Term-1*]

(*a*) 1.5 N/C (*b*) 1.5×10^{-16} N/C
(*c*) 3×10^{-10} N/C (*d*) 3 N/C

25. **A small object with charge q and weight mg is attached to one end of a string of length 'L' attached to a stationary support. The system is placed in a uniform horizontal electric field 'E', as shown in the accompanying figure. In the presence of the field, the string makes a constant angle θ with the vertical. The sign and magnitude of q is** **[*CBSE Sample Paper-2022, Term-1*]**



(*a*) positive with magnitude mg/E

(*b*) positive with magnitude $(mg/E)\tan\theta$

(*c*) negative with magnitude $mg/E \tan\theta$

(*d*) positive with magnitude $E\tan\theta/mg$

26. **A point charge situated at a distance 'r' from a short electric dipole on its axis, experiences a force $\vec{F}$. If the distance of the charge is '$2r$', the force on the charge will be** **[*CBSE 2023 (55/1/1)*]**

(*a*) $\dfrac{\vec{F}}{16}$ (*b*) $\dfrac{\vec{F}}{8}$

(*c*) $\dfrac{\vec{F}}{4}$ (*d*) $\dfrac{\vec{F}}{2}$

27. **The magnitude of the electric field due to a point charge object at a distance of 4.0 m is 9 N/C. From the same charged object the electric field of magnitude, 16NC^{-1} will be at a distance of** **[*CBSE 2023 (55/2/1)*]**

(*a*) 1 m (*b*) 2 m (*c*) 3 m (*d*) 6 m

28. **An electron experiences n forece $(1{\cdot}6 \times 10^{-16}\text{ N})\,\hat{i}$ in an electric field $\vec{\text{E}}$. The electric field is $\vec{\text{E}}$ is** **[*CBSE 2023 (55/3/1)*]**

(*a*) $(1.0\times10^{3}\text{NC}^{-1})\hat{i}$ (*b*) $-(1.0\times10^{3}\text{NC}^{-1})\hat{i}$

(*c*) $(1.0\times10^{-3}\text{NC}^{-1})\hat{i}$ (*d*) $-(1.0\times10^{-3}\text{NC}^{-1})\hat{i}$

29. **Two charges q_1 and q_2 are placed at the centres of two spherical counducting shells of radius r_1 and r_2 respectively. The shells are arranged such that their centres are $d\,[>(r_1+r_2)]$ distance apart. The force on q_2 due to q_1 is:** **[*CBSE 2023 (55/4/1)*]**

(*a*) $\dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{d^2}$ (*b*) $\dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{(d-r_1)^2}$

(*c*) zero (*d*) $\dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{[d-(r_1+r_2)]^2}$

30. **An electric dipole of length 2 cm is placed at an angle of 30° with an electric field 2×10^5 N/C. If the dipole experiences a torque of 8×10^{-3} Nm, the magnitude of either charge of the dipole, is** **[*CBSE 2023 (55/4/1)*]**

(*a*) 4 μC (*b*) 7 μC

(*c*) 8 mC (*d*) 2 mC

Answers

1. (*d*)	**2.** (*d*)	**3.** (*b*)	**4.** (*a*)	**5.** (*d*)	**6.** (*a*)	**7.** (*c*)
8. (*c*)	**9.** (*a*)	**10.** (*c*), (*d*)	**11.** (*a*)	**12.** (*b*)	**13.** (*b*)	**14.** (*b*)
15. (*c*)	**16.** (*b*)	**17.** (*c*)	**18.** (*c*)	**19.** (*b*)	**20.** (*a*)	**21.** (*a*)
22. (*d*)	**23.** (*a*)	**24.** (*d*)	**25.** (*b*)	**26.** (*b*)	**27.** (*c*)	**28.** (*b*)
29. (*a*)	**30.** (*a*)					

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(a) *Both A and R are true and R is the correct explanation of A.*

(b) *Both A and R are true but R is not the correct explanation of A.*

(c) *A is true but R is false.*

(d) *A is false and R is also false.*

1. **Assertion** (*A*) : A negative charge in an electric field moves along the direction of the electric field.
   Reason (*R*) : On a negative charge a force acts in the direction of the electric field.
   [*CBSE 2022 (55/2/4), Term-1*]
2. **Assertion** (*A*) : Charge is quantized because only integral number of electrons can be transferred.
   Reason (*R*) : There is no possibility of transfer of some fraction of electron.
3. **Assertion** (*A*) : In a non-uniform electric field, a dipole will have translatory as well as rotatory motion.
   Reason (*R*) : In a non-uniform electric field, a dipole experiences a force as well as torque.
   [*CBSE Sample Paper 2021*]
4. **Assertion** (*A*) : Electrostatic field lines start at positive charges and end at negative charges.
   Reason (*R*) : Field lines are continuous curves without any breaks and they form closed loop.
5. **Assertion** (*A*) : Electrons moves away from a region of lower potential to a region of higher potential.
   Reason (*R*) : An electron has a negative charge.
6. **Assertion** (*A*) : All the charge in a conductor gets distributed on whole of its outer surface.
   Reason (*R*) : In a dynamic system, charges try to keep their potential energy minimum.
   [*AIIMS 2018*]
7. **Assertion** (*A*) : When a body acquires negative charge, its mass decreases.
   Reason (*R*) : A body acquires positive charge when it gains electrons.
8. **Assertion** (*A*) : Surface charge density of an irregularly shaped conductor is non-uniform.
   Reason (*R*) : Surface density is defined as charge per unit area.
9. **Assertion** (*A*) : Total flux through a closed surface is zero if no charge is enclosed by the surface.
   Reason (*R*) : Gauss law is true for any closed surface, no matter what its shape or size is.
10. **Assertion** (*A*) : If a proton and an electron are placed in the same uniform electric field, they experience different acceleration.
    Reason (*R*) : Electric force on a test charge is independent of its mass.

Answers

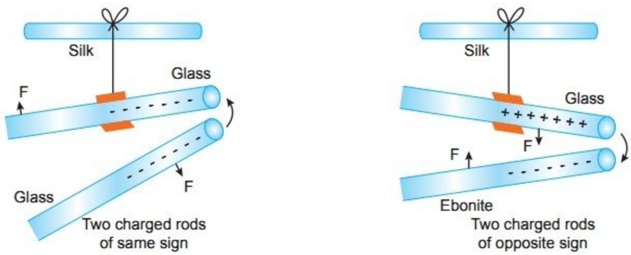
1. (*d*) **2.** (*b*) **3.** (*a*) **4.** (*c*) **5.** (*a*) **6.** (*a*) **7.** (*d*)
8. (*b*) **9.** (*a*) **10.** (*b*)

Case-based/Passage-based Questions

Read the paragraph given below and answer the questions that follow:

Frictional Electricity: Induction

The easiest way to experience electric charge is to rub certain solid bodies against each other. Long ago, around 600 BC, the Greeks knew that when amber is rubbed with wool, it acquires the property of attracting light objects such as small pieces of paper. This is because amber becomes electrically charged. If we pass a comb through dry hair, the comb becomes electrically charged and can attract small pieces of paper. An automobile becomes charged when it travels through the air. A paper sheet becomes charged when it passes through a printing machine. A gramophone record becomes charged when cleaned with a dry cloth.

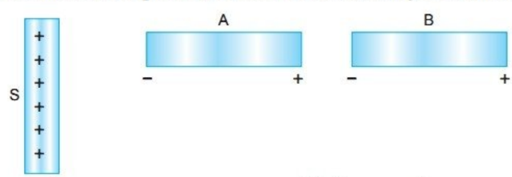


The explanation of appearance of electric charge on rubbing is simple. All material bodies contain large number of electrons and equal number of protons in their normal state. When rubbed against each other, some electrons from one body may pass on to the other body. The body that receives the extra electrons becomes negatively charged and the body that donates the electrons becomes positively charged because it has more protons than electrons. Thus, when a glass rod is rubbed with a silk cloth, electrons are transferred from the glass rod to the silk cloth. The glass rod becomes positively charged and the silk cloth becomes negatively charged.

(*i*) Charge Q is distributed to two different metallic spheres having radii R and $2R$ such that both spheres have equal surface charge density. Then charge on larger sphere is

(*a*) $\frac{4Q}{5}$ (*b*) $\frac{3Q}{5}$ (*c*) $\frac{5Q}{4}$ (*d*) $\frac{Q}{5}$

(*ii*) A large non-conducting sheet S is given a uniform charge density. Two uncharged small metal rods A and B are kept near the sheet as shown in figure. Which of the following is true?



(*a*) S attracts A (*b*) S attracts B

(*c*) A attracts B (*d*) All of these

(*iii*) Charge on a body which carries 300 excess electrons is

(*a*) -4.8×10^{-18} C (*b*) 4.8×10^{-18} C

(*c*) -4.8×10^{-17} C (*d*) 4.8×10^{-17} C

(iv) **Which of the following cannot be true about properties of charge?**

(a) Charges can be created or destroyed in equal and unlike pairs only.

(b) Proper sign have to be used while adding the charges in a system.

(c) Excess of electrons over protons in a body is responsible for positive charge of the body.

(d) It is not possible to create or destroy net charge carried by an isolated system.

OR

The cause of charging is

(a) actual transfer of neutrons (b) actual transfer of electrons

(c) actual transfer of protons (d) none of these

Explanations

(i) (a) If q, and q' are charges on sphere of radii R and $2R$, then surface charge density will be same.

i.e., $$\sigma = \sigma'$$

$$\frac{q}{4\pi R^2} = \frac{q'}{4\pi (2R)^2} \quad \Rightarrow q' = 4q \qquad \left[\because \sigma = \frac{Q}{A}\right]$$

As $q + q' = Q \;\Rightarrow\; q + 4q = Q \;\Rightarrow\; q = \dfrac{Q}{5}$

$$\therefore \qquad q' = \frac{4Q}{5}$$

(ii) (d) If the sheet S is given some positive charge density, then by induction, negative charge develop on ends of A and B, closer to S and an equal positive charge develops on farther ends of A and B as shown in figure. So, S attracts both A and B. Also, A attracts B.

(iii) (c) According to quantization of charge, $Q = ne$

Hence $n = 300$, $e = -1.6 \times 10^{-19}$ C

So, $Q = 300 \times (-1.6 \times 10^{-19}) = -4.8 \times 10^{-17}$C

(iv) (c) Excess of electrons over protons in a body is responsible for negative charge of the body.

OR

(b) The charging of body is due to transfer of electrons only.

CONCEPTUAL QUESTIONS

Q. 1. Why is the direction of the electric field due to a charged conducting sphere at any point perpendicular to its surface? *[CBSE 2019 (55/2/2)]*

Ans. If electric field is not perpendicular but has a component tangential to the surface of the conductor, it will exert force on charge and make them more. It means electrostatic condition is violated. **1**

[CBSE Marking Scheme 2019 (55/2/2)]

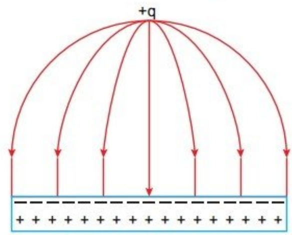
Q. 2. Two electric field lines cannot cross each other. Also, they cannot form closed loops. Give reasons. *[CBSE 2020 (55/2/1)]*

Ans. (i) Two electric field lines never cross each other because if they do so there will be two directions of electric field at the point of intersection which is not possible.

(ii) Since the electric field lines start from positive charge and terminate at the negative charge hence closed loops are not possible.

Q. 3. Draw the pattern of electric field lines when a point charge $+q$ is kept near an uncharged conducting plate. *[CBSE 2019 (55/1/3)]*

Ans.



Q. 4. Does the charge given to a metallic sphere depend on whether it is hollow or solid? Give reason for your answer. *[CBSE 2017 (55/1/1)]*

Ans. No, ½

Because the charge resides only on the surface of the conductor. ½

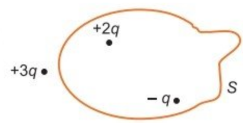
[CBSE Marking Scheme 2017 (55/1/1)]

Q. 5. Two identical conducting balls A and B have charges $-Q$ and $+3Q$ respectively. They are brought in contact with each other and then separated by a distance d apart. Find the nature of the Coulomb force between them. *[CBSE 2019 (55/4/1)]*

Ans. Final charge on balls A and B $= \dfrac{3Q - Q}{2} = Q$

The nature of the coulomb force between them is **repulsive**.

Q. 6. Fig. shows three point charges $+2q$, $-q$ and $+3q$. The charges $+2q$ and $-q$ are enclosed within a surface 'S'. What is the electric flux due to this configuration through the surface 'S'? *[CBSE Delhi 2010]*



Ans. Electric flux $= \dfrac{1}{\varepsilon_0} \times$ (Net charge enclosed within the surface)

$$= \frac{1}{\varepsilon_0}(2q - q) = \frac{q}{\varepsilon_0}$$

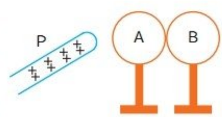
Q. 7. What is the electric flux through a cube of side 1 cm which encloses an electric dipole? *[CBSE Delhi 2015]*

Ans. Net electric flux is zero.

Reason : (*i*) Independent to the shape and size.

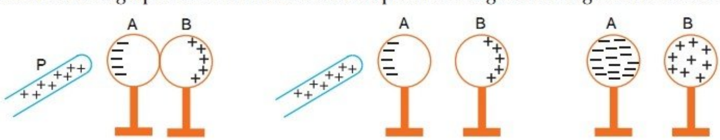
(*ii*) Net charge of the electric dipole is zero.

Q. 8. Two metallic spheres A and B kept on insulating stands are in contact with each other. A positively charged rod P is brought near the sphere A as shown in the figure. The two spheres are separated from each other, and the rod P is removed. What will be the nature of charges on spheres A and B? *[CBSE 2019 (55/3/1)]*



Ans.
- Sphere A will be negatively charged.
- Sphere B will be positively charged.

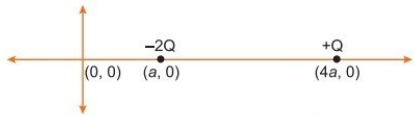
Explanation: If positively charged rod P is brought near metallic sphere A due to induction negative charge starts building up at the left surface of A and positive charge on the right surface of B.



If the two spheres are separated from each other, the two spheres are found to be oppositely charged. If rod P is removed, the charges on spheres rearrange themselves and get uniformly distributed over them.

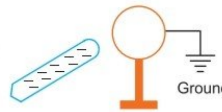
Q. 9. Two charges of magnitudes – $2Q$ and $+Q$ are located at points (a, 0) and (4a, 0) respectively. What is the electric flux due to these charges through a sphere of radius '3a' with its centre at the origin? [*CBSE (AI) 2013*]

Ans. Electric flux, $\phi = \dfrac{-2Q}{\varepsilon_0}$



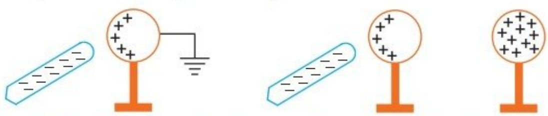
Concept: Imagine a sphere of radius 3a about the origin and observe that only charge $-2Q$ is inside the sphere.

Q. 10. A metal sphere is kept on an insulating stand. A negatively charged rod is brought near it, then the sphere is earthed as shown. On removing the earthing, and taking the negatively charged rod away, what will be the nature of charge on the sphere? Give reason for your answer. [*CBSE 2019 (55/3/1)*]



Ans. The sphere will be positively charged due to electrostatic induction.

Explanation: When a negatively charged rod is brought near a metal sphere, the electrons will flow to the ground while the positive charges at the near end will remain held there due to the attractive force of the negative charge on the rod. On disconnecting the sphere from the ground, the positive charge continues to be held at the near end. On removing the electrified rod, the positive charge will spread uniformly over the sphere.

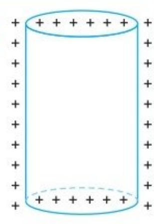


Q. 11. How does the electric flux due to a point charge enclosed by a spherical Gaussian surface get affected when its radius is increased? [*CBSE 2016 (55/1/1)*]

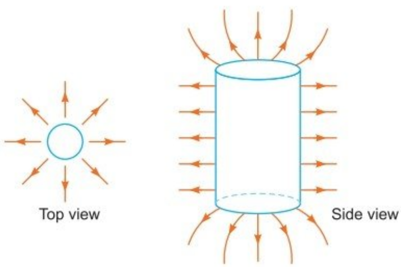
Ans. Electric flux remains unaffected. **1**

[*CBSE Marking Scheme 2016 (55/1/1)*]

Q. 12. Sketch the electric field lines for a uniformly charged hollow cylinder shown in figure. [*NCERT Exemplar*][*HOTS*]



Ans.



Q. 13. What is the nature of electrostatic force between two point electric charges q_1 and q_2 if

(*a*) $q_1 + q_2 > 0$? **(*b*) $q_1 + q_2 < 0$?**

Ans. (*a*) If both q_1 and q_2 are positive, the electrostatic force between these will be repulsive.

However, if one of these charges is positive and is greater than the other negative charge, the electrostatic force between them will be attractive.

Thus, the nature of force between them can be repulsive or attractive.

(*b*) If both q_1 and q_2 are –ve, the force between these will be repulsive.

However, if one of them is –ve and it is greater in magnitude than the second +ve charge, the force between them will be attractive.

Thus, the nature of force between them can be repulsive or attractive.

Q. 14. The dimensions of an atom are of the order of an Angstrom. Thus there must be large electric fields between the protons and electrons. Why, then is the electrostatic field inside a conductor zero? **[*NCERT Exemplar*]**

Ans. The electric fields bind the atoms to neutral entity. Fields are caused by excess charges. There can be no excess charge on the inner surface of an isolated conductor. So, the electrostatic field inside a conductor is zero.

Q. 15. An arbitrary surface encloses a dipole. What is the electric flux through this surface? **[*NCERT Exemplar*]**

Ans. Net charge on a dipole = $-q + q = 0$. According to Gauss's theorem, electric flux through the surface,

$$\phi = \frac{q}{\varepsilon_0} = \frac{0}{\varepsilon_0} = 0$$

Very Short Answer Questions

Each of the following questions are of 2 marks.

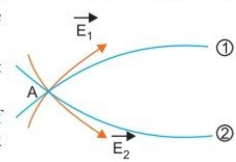
Q. 1. (*a*) An electrostatic field line is a continuous curve. That is, a field line cannot have sudden breaks. Why is it so?

(*b*) Explain why two field lines never cross each other at any point. **[*CBSE (AI) 2014*]**

Ans. (*a*) An electrostatic field line is the path of movement of a positive test charge ($q_0 \to 0$)

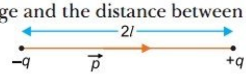
A moving charge experiences a continuous force in an electrostatic field, so an electrostatic field line is always a continuous curve.

(*b*) Two electric lines of force can never cross each other because if they cross, there will be two directions of electric field at the point of intersection (say *A*); which is impossible.



Q. 2. Define electric dipole moment. Is it a scalar or a vector quantity? What are its SI unit? **[*CBSE Sample Paper 2021, (AI) 2011, 2013, (F) 2009, 2012, 2013*]**

Ans. The electric dipole moment is defined as the product of either charge and the distance between the two charges. Its direction is from negative to positive charge.



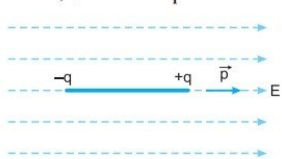
i.e., $|\vec{p}| = q(2l)$

Electric dipole moment is a vector quantity.

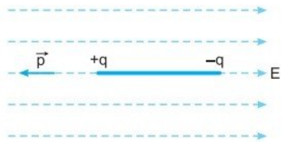
Its SI unit is coulomb-metre.

Q. 3. Depict the orientation of the dipole in (*a*) stable, (*b*) unstable equilibrium in a uniform electric field. **[*CBSE Delhi 2017*]**

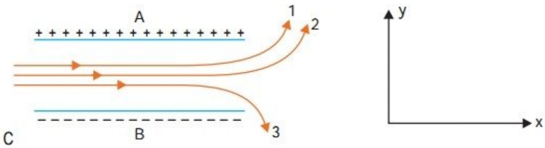
Ans. (*a*) Stable equilibrium, $\theta = 0°$ $\vec{P}$ is parallel to $\vec{E}$



(*b*) Unstable equilibrium, $\theta = 180°$ $\vec{P}$ is anti parallel to $\vec{E}$



Q. 4. The figure shows tracks of three charged particles in a uniform electrostatic field. Give the signs of the three charges. Which particle has the highest charge to mass ratio? [*NCERT*]



Ans. A positively charged particle is deflected towards a negative plate and a negatively charged particle towards a positive plate and shows a parabolic path.

From fig. it is clear that the particles (1) and (2) are deflected towards positive plate; hence, they carry **negative charges**.

Particle (3) is deflected along negative plate, so it carries **positive charge**.

The transverse deflection in a given electric field is

$$y = \frac{1}{2}at^2, \text{ where } a = \frac{qE}{m} \text{ and } t = \left(\frac{x}{u}\right)$$

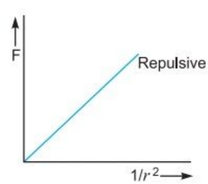
So $$y = \frac{1}{2}\left(\frac{q}{m}\right)\frac{E\,x^2}{u^2} \propto \frac{q}{m}.$$

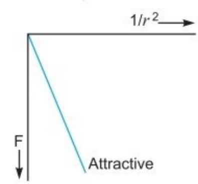
From fig., it is obvious that the transverse deflection is the maximum for particle (3), hence, particle (3) has the highest charge to mass ratio (q/m).

Q. 5. Plot a graph showing the variation of coulomb force (F) versus $\left(\frac{1}{r^2}\right)$, where r is the distance between the two charges of each pair of charges: (1 μC, 2 μC) and (2 μC, – 3 μC). Interpret the graphs obtained. [*CBSE (AI) 2011*]

Ans. $F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$.

The graph between F and $\frac{1}{r^2}$ is a straight line of slope $\frac{1}{4\pi\varepsilon_0}q_1 q_2$ passing through origin in both the cases.



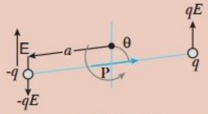


Since, magnitude of the slope is more for attraction, therefore, attractive force is greater than repulsive force.

Q. 6. Derive an expression for the torque acting on an electric dipole of dipole moment $\vec{P}$ placed in a uniform electric field $\vec{E}$. Write the direction along which the torque acts.

[*CBSE 2019 (55/5/1)*]

Ans.



½

Force on either charge, $F = qE$

Magnitude of torque = Either of force × ⊥ distance between them. ½

$$\tau = qE\ 2a \sin\theta$$

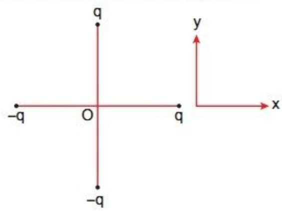
$$\Rightarrow \quad \tau = pE \sin\theta$$

$$\therefore \quad \vec{\tau} = \vec{P} \times \vec{E}$$ ½

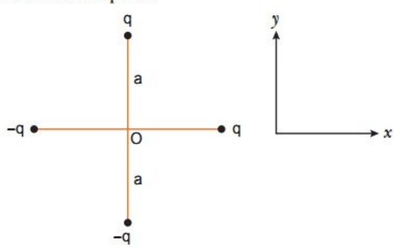
Direction is normal to the paper coming out of it. ½

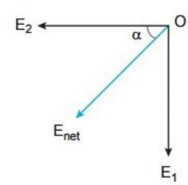
[CBSE Marking Scheme 2019 (55/5/1)]

Q. 7. Two identical dipoles are arranged in x-y plane as shown in the figure. Find the magnitude and the direction of net electric field at the origin O. *[CBSE 2023 (55/4/1)]*



Ans. Electric field at O due to both dipole.





$$\vec{E}_1 = \frac{kq}{a^2}(-\hat{j}-\hat{j}) = -\frac{2kq}{a^2}\hat{j}$$

$$\vec{E}_2 = \frac{kq}{a^2}(-\hat{i}-\hat{i}) = -\frac{2kq}{a^2}\hat{i}$$

So, net electric field at O,

$$|\vec{E}_{net}| = \sqrt{E_1^2 + E_2^2} = \sqrt{\left(\frac{2kq}{a^2}\right)^2 + \left(\frac{2kq}{a^2}\right)^2}$$

$$= \frac{2\sqrt{2}\,kq}{a^2}\ \text{NC}^{-1}$$

Also, $\tan\alpha = \dfrac{|\vec{E}_1|}{|\vec{E}_2|} = 1 \quad \Rightarrow \quad \alpha = 45°$

Hence, direction of $\vec{E}_{net}$ is 45° to its – x axis or 225° to + x-axis.

Q. 8. **(*a*) Define electric flux. Write its SI unit.**

(*b*) A spherical rubber balloon carries a charge that is uniformly distributed over its surface. As the balloon is blown up and increases in size, how does the total electric flux coming out of the surface change? Give reason. **[*CBSE (F) 2016*]**

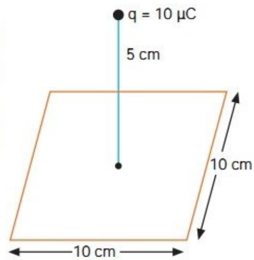
Ans. (*a*) Total number of electric field lines crossing a surface normally is called electric flux.

Its SI unit is Nm^2C^{-1} or Vm.

(*b*) Total electric flux through the surface $= \dfrac{q}{\varepsilon_0}$

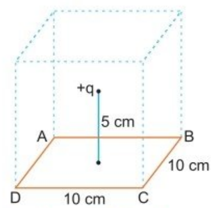
As charge remains unchanged when size of balloon increases, electric flux through the surface remains unchanged.

Q. 9. **A point charge + 10 μC is at a distance 5 cm directly above the centre of a square of side 10 cm as shown in figure. What is the magnitude of the electric flux through the square? [Hint: Think of the square as one face of a cube with edge 10 cm]** **[*NCERT*] [*HOTS*]**



Ans. Obviously the given square *ABCD* of side 10 cm is one face of a cube of side 10 cm. At the centre of this cube a charge $+q = 10\ \mu C$ is placed.

According to Gauss's theorem, the total electric flux through the six faces of cube $= \dfrac{q}{\varepsilon_0}$.



$\therefore$ Total electric flux through square,

$$\phi = \frac{1}{6}\frac{q}{\varepsilon_0}$$

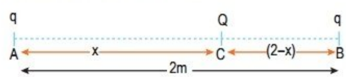
$$= \frac{1}{6} \times \frac{10 \times 10^{-6}}{8.85 \times 10^{-12}}$$

$$= \mathbf{1.88 \times 10^5\ Nm^2C^{-1}}.$$

Q. 10. **Two identical point charges, *q* each, are kept 2 m apart in air. A third point charge *Q* of unknown magnitude and sign is placed on the line joining the charges such that the system remains in equilibrium. Find the position and nature of *Q*.** **[*CBSE 2019 (55/1/1)*]**

Ans. System is in equilibrium therefore net force on each charge of system will be zero.

For the total force on 'Q' to be zero



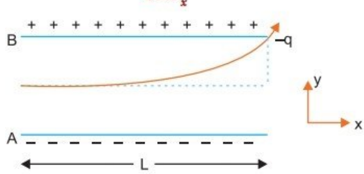
$$\frac{1}{4\pi\varepsilon_0}\frac{qQ}{x^2} = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{(2-x)^2}$$

$\Rightarrow \quad x = 2 - x \quad \Rightarrow \quad 2x = 2$

$\Rightarrow \quad \mathbf{x = 1\ m}$

For the equilibrium of charge "*q*" the nature of charge *Q* must be opposite to the nature of charge *q*.

Q. 11. **A particle of mass *m* and charge (–*q*) enters the region between the two charged plates initially moving along *X*-axis with speed v_x as shown in fig. The length of plate is *L* and an uniform electric field *E* is maintained between the plates. Show that the vertical deflection of the particle at the far edge of the plate is $\dfrac{qEL^2}{2mv_x^2}$.** **[*NCERT*] [*HOTS*]**



Ans. Force on particle towards upper plate B, $F_y = qE$ vertical acceleration of particle, $a_y = \frac{qE}{m}$.

Initial vertical velocity $v_y = 0$

Speed of particle along X-axis $= v_x$ (constant)

Time taken by particle between the plates, $t = \frac{L}{v_x}$

From relation, $s = ut + \frac{1}{2}at^2$

Vertical deflection, $y = 0 + \frac{1}{2}a_y t^2 = 0 + \frac{1}{2}\left(\frac{qE}{m}\right)\left(\frac{L}{v_x}\right)^2$

$$\therefore \qquad \boldsymbol{y = \frac{qEL^2}{2mv_x^2}}$$

Q. 12. Given a uniform electric field $\vec{E} = 5\times10^3\,\hat{i}$ N/C, find the flux of this field through a square of 10 cm on a side whose plane is parallel to the Y-Z plane. What would be the flux through the same square if the plane makes a 30° angle with the X-axis? ***[CBSE Delhi 2014]***

Ans. Here, $\vec{E} = 5\times10^3\,\hat{i}$ N/C, *i.e.*, field is along positive direction of X-axis.

Surface area, A = 10 cm × 10 cm = 0.10 m × 0.10 m = 10^{-2} m^2

(*i*) When plane is parallel to Y-Z plane, the normal to plane is along X-axis. Hence

$$\theta = 0°$$

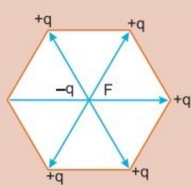
$$\therefore \qquad \phi = EA\cos\theta = 5\times10^3\times10^{-2}\cos 0° = \mathbf{50\ NC^{-1}\,m^2}$$

(*ii*) When the plane makes a 30° angle with the X-axis, the normal to its plane makes 60° angle with X-axis. Hence $\theta = 60°$,

$$\therefore \qquad \phi = EA\cos\theta = 5\times10^3\times10^{-2}\cos 60° = \mathbf{25\ NC^{-1}\,m^2}$$

Q. 13. Five point charges, each of charge $+q$ are placed on five vertices of a regular hexagon of side 'l'. Find the magnitude of the resultant force on a charge $-q$ placed at the centre of the hexagon. ***[CBSE 2019 (55/3/1)]***

Ans.



1

Alternatively:

The forces due to the charges placed diagonally opposite at the vertices of hexagon, on the charge -q cancel in pairs. Hence net force is due to one charge only.

Net Force, $|\vec{F}| = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{l^2}$ 1

[CBSE Marking Scheme 2019 (55/3/1)]

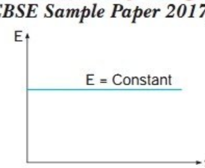
Q. 14. Represent graphically the variation of electric field with distance, for a uniformly charged plane sheet. ***[CBSE Sample Paper 2017]***

Ans. Electric field due to a uniformly charged plane sheet.

$$E = \frac{\sigma}{2\varepsilon_0}$$

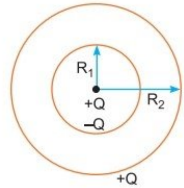
which is independent of distance.

So, it represents a straight line parallel to distance axis.



Q. 15. A metallic spherical shell has an inner radius R_1 and outer radius R_2. A charge Q is placed at the centre of the spherical cavity. What will be surface charge density on (*i*) the inner surface, and (*ii*) the outer surface? *[NCERT Exemplar]*

Ans. When a charge $+Q$ is placed at the centre of spherical cavity,
the charge induced on the inner surface $= -Q$
the charge induced on the outer surface $= +Q$

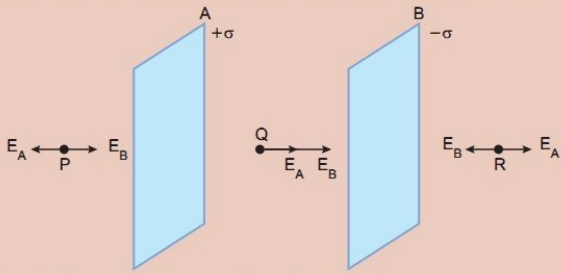


$\therefore$ Surface charge density on the inner surface $= \dfrac{-Q}{4\pi R_1^2}$

Surface charge density on the outer surface $= \dfrac{+Q}{4\pi R_2^2}$

Q. 16. Two large parallel plane sheets have uniform charge densities $+\sigma$ and $-\sigma$. Determine the electric field (*i*) between the sheets, and (*ii*) outside the sheets. *[CBSE 2019 (55/4/1)]*

Ans.



½

Now Electric field Intensity due to a plane sheet of charge

$$E = \frac{\sigma}{2\varepsilon_0}$$ ½

Here

$$E_A = \frac{+\sigma}{2\varepsilon_0} \text{ and } E_B = \frac{-\sigma}{2\varepsilon_0}$$

(*i*) Electric field at point Q (In between the sheets)

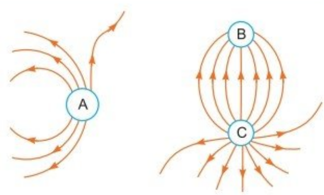
$$\vec{E} = \vec{E}_A + \vec{E}_B = \frac{\sigma}{2\varepsilon_0} + \frac{\sigma}{2\varepsilon_0} = \frac{\sigma}{\varepsilon_0}$$ ½

(*ii*) Field at the point P or R

$$\vec{E} = \vec{E}_A + \vec{E}_B = \frac{\sigma}{2\varepsilon_0} - \frac{\sigma}{2\varepsilon_0} = 0$$ ½

[CBSE Marking Scheme 2019 (55/4/1)]

Q. 17. The given figure shows the electric field lines around three point charges A, B and C.



(*a*) Which charges are positive?
(*b*) Which charge has the largest magnitude? Why?
(*c*) In which region or regions of the picture could the electric field be zero? Justify your answer.
(*i*) near A (*ii*) near B (*iii*) near C (*iv*) nowhere.

[NCERT Exemplar] [HOTS]

Ans. (*a*) Charges A and C are positive since lines of force emanate from them.
(*b*) Charge C has the largest magnitude since maximum number of field lines are associated with it.
(*c*) (*i*) near A.

Justification: There is no neutral point between a positive and a negative charge. A neutral point may exist between two like charges. From the figure we see that a neutral point exists between charges A and C. Also between two like charges the neutral point is closer to the charge with smaller magnitude. Thus, electric field is zero near charge A.

Q. 18. Two isolated metal spheres A and B have radii R and $2R$ respectively, and same charge q. Find which of the two spheres have greater energy density just outside the surface of the spheres.
[CBSE Sample Paper 2016]

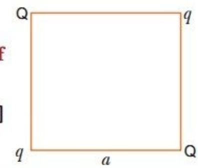
Ans. Energy density,

$$U = \frac{1}{2}\varepsilon_0 E^2$$

But, $E = \dfrac{\sigma}{\varepsilon_0} = \dfrac{Q}{A\varepsilon_0}$

$$\therefore \quad U = \frac{1}{2}\frac{\varepsilon_0 Q^2}{A^2\varepsilon_0^2} \Rightarrow U = \frac{Q^2}{2A^2\varepsilon_0} \Rightarrow \quad U \propto \frac{1}{A^2} \quad \Rightarrow \quad U_A > U_B$$

Q. 19. Four point charges Q, q, Q and q are placed at the corners of a square of side 'a' as shown in the figure. Find the resultant electric force on a charge Q. *[CBSE 2018 (55/1)]*



Ans. Let us find the force on the charge Q at the point C.

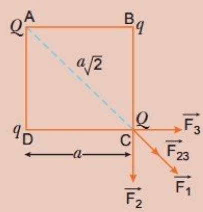
Force due to the other charge Q

$$F_1 = \frac{1}{4\pi\varepsilon_0}\frac{Q^2}{(a\sqrt{2})^2} = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q^2}{2a^2}\right)(\text{along } AC)$$ ½

Force due to the charge q (at B),

$$F_2 = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{a^2} \ (\text{along } BC)$$

Force due to the charge q (at D),



$$F_3 = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{a^2} \ (\text{along } DC)$$ ½

Resultant of these two equal forces

$$F_{23} = \frac{1}{4\pi\varepsilon_0}\frac{qQ(\sqrt{2})}{a^2} \ (\text{along } AC)$$

$\therefore$ Net force on charge Q (at point C) ½

$$F = F_1 + F_{23} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{a^2}\left[\frac{Q}{2} + \sqrt{2}q\right]$$ ½

This force is directed along AC. (For the charge Q, at the point A, the force will have the same magnitude but will be directed along CA)

[**Note:** Don't deduct marks if the student does not write the direction of the net force, F]
[CBSE Marking Scheme 2018 (55/1)]

Q. 20. Three point charges q, $-4q$ and $2q$ are placed at the vertices of an equilateral triangle ABC of side 'l' as shown in the figure. Obtain the expression for the magnitude of the resultant electric force acting on the charge q. *[CBSE 2018 (55/1)]*

Justification: There is no neutral point between a positive and a negative charge. A neutral point may exist between two like charges. From the figure we see that a neutral point exists between charges A and C. Also between two like charges the neutral point is closer to the charge with smaller magnitude. Thus, electric field is zero near charge A.

Q. 18. Two isolated metal spheres A and B have radii R and $2R$ respectively, and same charge q. Find which of the two spheres have greater energy density just outside the surface of the spheres. *[CBSE Sample Paper 2016]*

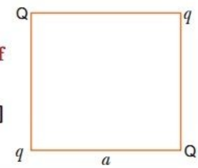
Ans. Energy density,

$$U = \frac{1}{2}\varepsilon_0 E^2$$

But, $E = \dfrac{\sigma}{\varepsilon_0} = \dfrac{Q}{A\varepsilon_0}$

$$\therefore \quad U = \frac{1}{2}\frac{\varepsilon_0 Q^2}{A^2\varepsilon_0^2} \Rightarrow U = \frac{Q^2}{2A^2\varepsilon_0} \Rightarrow \quad U \propto \frac{1}{A^2} \quad \Rightarrow \quad U_A > U_B$$

Q. 19. Four point charges Q, q, Q and q are placed at the corners of a square of side 'a' as shown in the figure. Find the resultant electric force on a charge Q. *[CBSE 2018 (55/1)]*



Ans. Let us find the force on the charge Q at the point C.

Force due to the other charge Q

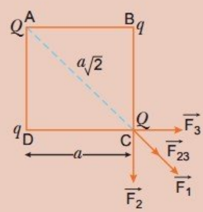
$$F_1 = \frac{1}{4\pi\varepsilon_0}\frac{Q^2}{(a\sqrt{2})^2} = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q^2}{2a^2}\right)\text{(along } AC) \qquad ½$$

Force due to the charge q (at B),

$$F_2 = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{a^2} \text{ (along } BC)$$

Force due to the charge q (at D),

$$F_3 = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{a^2} \text{ (along } DC) \qquad ½$$



Resultant of these two equal forces

$$F_{23} = \frac{1}{4\pi\varepsilon_0}\frac{qQ(\sqrt{2})}{a^2} \text{ (along } AC)$$

$\therefore$ Net force on charge Q (at point C) ½

$$F = F_1 + F_{23} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{a^2}\left[\frac{Q}{2} + \sqrt{2}q\right] \qquad ½$$

This force is directed along AC. (For the charge Q, at the point A, the force will have the same magnitude but will be directed along CA)

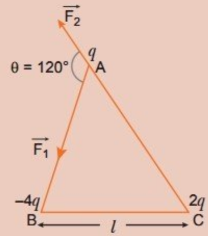
[**Note:** Don't deduct marks if the student does not write the direction of the net force, F]

[CBSE Marking Scheme 2018 (55/1)]

Q. 20. Three point charges q, $-4q$ and $2q$ are placed at the vertices of an equilateral triangle ABC of side 'l' as shown in the figure. Obtain the expression for the magnitude of the resultant electric force acting on the charge q. *[CBSE 2018 (55/1)]*

Ans. Force on charge q due to the charge $-4q$

$$F_1 = \frac{1}{4\pi\varepsilon_0}\left(\frac{4q^2}{l^2}\right), \text{ along } AB$$ ½



Force on the charge q, due to the charge $2q$

$$F_2 = \frac{1}{4\pi\varepsilon_0}\left(\frac{2q^2}{l^2}\right), \text{ along } CA$$

The forces F_1 and F_2 are inclined to each other at an angle of 120°

Hence, resultant electric force on charge q,

$$F = \sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos\theta}$$ ½

$$= \sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos 120°}$$

$$= \sqrt{F_1^2 + F_2^2 - F_1F_2}$$ ½

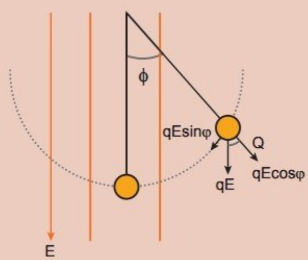
$$= \left(\frac{1}{4\pi\varepsilon_0}\frac{q^2}{l^2}\right)\sqrt{16+4-8}$$

$$= \frac{1}{4\pi\varepsilon_0}\left(\frac{2\sqrt{3}q^2}{l^2}\right)$$ ½

[*CBSE Marking Scheme 2018 (55/1)*]

Q. 21. A simple pendulum consists of a small sphere of mass *m* suspended by a thread of length *l*. The sphere carries a positive charge *q*. The pendulum is placed in a uniform electric field of strength *E* directed vertically downwards. Find the period of oscillation of the pendulum due to the electrostatic force acting on the sphere, neglecting the effect of the gravitational force.
[*CBSE 2019 (55/3/1)*]

Ans.



½

Restoring force,

$$F_r = -qE\sin\phi$$ ½

$\Rightarrow \quad ma = -qE\sin\phi$

When ϕ is small, $\sin\phi \simeq \phi$

$\Rightarrow \quad ma = -qE\phi$

$\Rightarrow \quad m\dfrac{d^2x}{dt} = -qE\dfrac{x}{l}$

$\Rightarrow \quad \dfrac{d^2x}{dt^2} = -q\dfrac{E}{m}\dfrac{x}{l}$ ½

Comparing with equation of linear SHM

$$\frac{d^2x}{dt^2} = -\omega^2 x \quad \Rightarrow \omega^2 = \frac{qE}{ml}$$

$$\Rightarrow \qquad \omega = \sqrt{\frac{qE}{ml}}$$

$$\therefore \qquad T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{ml}{qE}}$$ ½

Alternatively: The student can use angular SHM intermediate also. Full marks to be awarded for correct answer even without intermediate steps.

[CBSE Marking Scheme 2019 (55/3/1)]

Q. 22. An electric dipole of length 2 cm is placed with its axis making an angle of 60° with respect to uniform electric field of 10^5 N/C.
If it experiences a torque of $8\sqrt{3}$ Nm, calculate the magnitude of charge on the dipole, and its potential energy. *[CBSE Sample Paper 2021]*

Ans. Here, $2l = 2 \text{ cm} = 2 \times 10^{-2}$ m

$\theta = 60°, E = 10^5 \text{N/C}, \tau = 8\sqrt{3}$ Nm

Using $\tau = pE \sin\theta$

$\tau = 2\,qlE \sin\theta$

$$q = \frac{\tau}{2\,l\,E\sin\theta} = \frac{8\sqrt{3}\times 2}{2\times 10^{-2}\times 10^5\times\sqrt{3}} = 8\times 10^{-3}\,\text{C}$$

Potential energy $= -\,pE\cos\theta = -2qlE\cos\theta$

$$= -2\times 10^{-2}\times 8\times 10^{-3}\times 10^5\times\frac{1}{2} = \mathbf{8\ J}$$

Q. 23. Two point charges $q_1 = +1\,\mu$C and $q_2 = +4\,\mu$C are placed 2 m apart in air. At what distance from q_1 along the line joining the two charges, will the net electric field be zero?

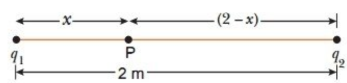
[CBSE 2020 (55/3/1)]

Ans. The electric field at point P due to q_1,

$$E_1 = \frac{kq_1}{x^2}$$

The electric field at point P due to q_2,

$$E_2 = \frac{kq_2}{(2-x)^2}$$



At point P, net electric field is zero,

$$\Rightarrow \qquad E_1 = E_2$$

$$\Rightarrow \qquad \frac{kq_1}{x^2} = \frac{kq_2}{(2-x)^2} \qquad \Rightarrow \qquad \frac{1}{x^2} = \frac{4}{(2-x)^2}$$

$$\Rightarrow \qquad \frac{1}{x} = \frac{2}{(2-x)} \qquad \Rightarrow \qquad (2-x) = 2x$$

$$\Rightarrow \qquad 3x = 2$$

$$\therefore \qquad x = \mathbf{\frac{2}{3}\ m}$$

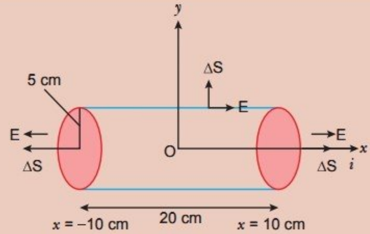
Q. 24. An electric field is uniform and acts along $+x$ direction in the region of positive x. It is also uniform with the same magnitude but acts in $-x$ direction in the region of negative x. The value of the field is $E = 200$ N/C for $x > 0$ and $E = -200$ N/C for $x < 0$. A right circular cylinder of length 20 cm and radius 5 cm has its centre at the origin and its axis along the x-axis so that one flat face is at $x = +10$ cm and the other is at $x = -10$ cm.

Find:

(*i*) **The net outward flux through the cylinder.**

(*ii*) **The net charge present inside the cylinder.** [*CBSE 2020 (55/1/1)*]

Ans. (*i*)



The net outward flux through cylinder,

$$\phi = EA + EA = 2EA \quad \text{where, } A = \pi r^2$$ ½

$$\therefore \quad \phi = 2 \times 200 \times 3.14 \times 0.05 \times 0.05$$

$$= 3.14 \text{ NC}^{-1}\text{m}^2$$ ½

(*ii*) The net charge present inside the cylinder,

$$q = \varepsilon_0 \phi$$

$$q = 8.854 \times 3.14 \times 10^{-12}$$ ½

$$= 2.78 \times 10^{-11} \text{ C}$$ ½

[*CBSE Marking Scheme 2020 (55/1/1)*]

Short Answer Questions

Each of the following questions are of 3 marks.

Q. 1. Two charged conducting spheres of radii *a* and *b* are connected to each other by a wire. Find the ratio of the electric fields at their surfaces. [*CBSE 2023 (55/2/1)*]

Ans. Two charged conducting spheres are connected to a wire then their potential on the surfaces are same.

$$\left[\text{Since } V = \frac{kq}{r}\right]$$

i.e., $V_1 = V_2$

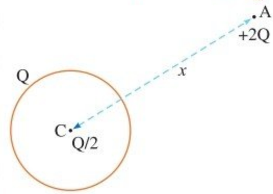
$$\frac{kq_a}{a} = \frac{kq_b}{b} \Rightarrow \frac{q_a}{q_b} = \frac{a}{b}$$

Also, we know, $E = \dfrac{kq}{r^2}$ (for point change)

then, $E_a = \dfrac{kq_a}{a^2}$, and $E_b = \dfrac{kq_b}{b^2}$

$$\text{Ratio,} \quad \frac{E_a}{E_b} = \frac{\dfrac{kq_a}{a^2}}{\dfrac{kq_b}{b^2}} = \frac{b^2}{a^2} \times \frac{q_a}{q_b} = \boldsymbol{\frac{b}{a}}.$$

Q. 2. A thin metallic spherical shell of radius R carries a charge Q on its surface. A point charge $\frac{Q}{2}$ is placed at the centre C and another charge $+2Q$ is placed outside the shell at A at a distance x from the centre as shown in the figure.



(i) Find the electric flux through the shell.

(ii) State the law used.

(iii) Find the force on the charges at the centre C of the shell and at the point A. **[CBSE East 2016]**

Ans. (i) Electric flux through a Gaussian surface, $\phi = \dfrac{\text{Total enclosed charge}}{\varepsilon_0}$

Net charge enclosed inside the shell, $q = 0$

$\therefore$ Electric flux through the shell, $\phi = \dfrac{q}{\varepsilon_0} = 0$

(ii) **Gauss's Law:** Electric flux through a Gaussian surface is $\dfrac{1}{\varepsilon_0}$ times the net charge enclosed within it.

Mathematically, $\oint \vec{E}.\vec{ds} = \dfrac{1}{\varepsilon_0} \times q$

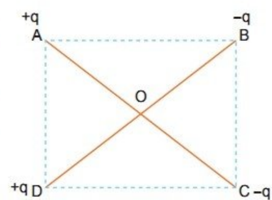
(iii) We know that electric field or net charge inside the spherical conducting shell is zero. Hence, the force on charge $\dfrac{Q}{2}$ is zero.

Force on charge at A, $F_A = \dfrac{1}{4\pi\varepsilon_0} \dfrac{2Q\left(Q + \dfrac{Q}{2}\right)}{x^2} = \dfrac{1}{4\pi\varepsilon_0} \dfrac{3Q^2}{x^2}$

Q. 3. (a) The distance of a far off point on the equatorial plane of an electric dipole is halved. How will the electric field be affected for the dipole?

(b) Two identical electric dipoles are placed along the diagonals of a square $ABCD$ of side $\sqrt{2}$ m as shown in the figure. Obtain the magnitude and direction of the net electric field at the centre (O) of the square.

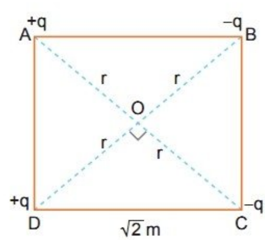
[CBSE 2023 (55/1/1)]



Ans. (a) If $r' = \dfrac{r}{2}$

Then, $E'_{eq} = \dfrac{kp}{(r')^3} = \dfrac{kp}{\left(\dfrac{r}{2}\right)^3} = \dfrac{8kp}{r^3} = 8\,E_{eq}$.

Hence, electric field at new position at equatorial line becomes 8 times of its initial value.



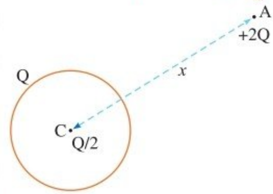
(b) Here, $AB = BC = CD = AD = \sqrt{2}$ m and

$q_A = q_D = +q, q_B = q_C = -q$

Electric field due to A and C at O,

$$E_1 = E_A + E_C = \frac{kq}{r^2} + \frac{kq}{r^2} = \frac{kq}{(1)^2} + \frac{kq}{(1)^2} = 2kq \text{ NC}^{-1} \qquad \left[r = \sqrt{2}\sin 45° = \frac{\sqrt{2}}{\sqrt{2}} = 1\text{ m}\right]$$

Q. 2. A thin metallic spherical shell of radius R carries a charge Q on its surface. A point charge $\frac{Q}{2}$ is placed at the centre C and another charge $+2Q$ is placed outside the shell at A at a distance x from the centre as shown in the figure.



(*i*) Find the electric flux through the shell.

(*ii*) State the law used.

(*iii*) Find the force on the charges at the centre C of the shell and at the point A. [*CBSE East 2016*]

Ans. (*i*) Electric flux through a Gaussian surface, $\phi = \dfrac{\text{Total enclosed charge}}{\varepsilon_0}$

Net charge enclosed inside the shell, $q = 0$

$\therefore$ Electric flux through the shell, $\phi = \dfrac{q}{\varepsilon_0} = 0$

(*ii*) **Gauss's Law:** Electric flux through a Gaussian surface is $\dfrac{1}{\varepsilon_0}$ times the net charge enclosed within it.

Mathematically, $\oint \vec{E}.\vec{ds} = \dfrac{1}{\varepsilon_0} \times q$

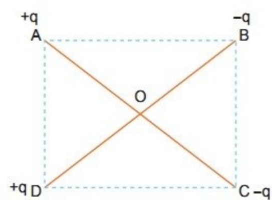
(*iii*) We know that electric field or net charge inside the spherical conducting shell is zero. Hence, the force on charge $\dfrac{Q}{2}$ is zero.

Force on charge at A, $F_A = \dfrac{1}{4\pi\varepsilon_0} \dfrac{2Q\left(Q + \frac{Q}{2}\right)}{x^2} = \dfrac{1}{4\pi\varepsilon_0} \dfrac{3Q^2}{x^2}$

Q. 3. (*a*) The distance of a far off point on the equatorial plane of an electric dipole is halved. How will the electric field be affected for the dipole?

(*b*) Two identical electric dipoles are placed along the diagonals of a square *ABCD* of side $\sqrt{2}$ m as shown in the figure. Obtain the magnitude and direction of the net electric field at the centre (O) of the square.

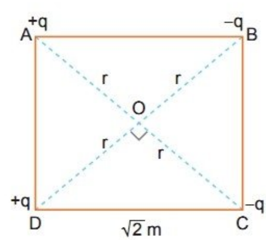
[*CBSE 2023 (55/1/1)*]



Ans. (*a*) If $r' = \dfrac{r}{2}$

Then, $E'_{eq} = \dfrac{kp}{(r')^3} = \dfrac{kp}{\left(\frac{r}{2}\right)^3} = \dfrac{8kp}{r^3} = 8\,E_{eq}$.

Hence, electric field at new position at equatorial line becomes 8 times of its initial value.



(*b*) Here, $AB = BC = CD = AD = \sqrt{2}$ m and

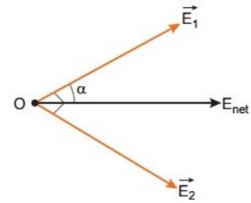
$q_A = q_D = +q, q_B = q_C = -q$

Electric field due to A and C at O,

$$E_1 = E_A + E_C = \frac{kq}{r^2} + \frac{kq}{r^2} = \frac{kq}{(1)^2} + \frac{kq}{(1)^2} = 2kq \text{ NC}^{-1} \qquad \left[r = \sqrt{2}\sin 45^\circ = \frac{\sqrt{2}}{\sqrt{2}} = 1\text{ m}\right]$$

Again, electric field due to D and B,

$$E_2 = E_D + E_B = \frac{kq}{(r)^2} + \frac{kq}{(r)^2} = \frac{kq}{(1)^2} + \frac{kq}{(1)^2} = 2kq\ \text{NC}^{-1}.$$



So, $E_{\text{net}} = \sqrt{E_1^{\,2} + E_2^{\,2}}$

$= \sqrt{(2kq)^2 + (2kq)^2}$

$= \mathbf{2\sqrt{2}\ kq\ NC^{-1}}$

For direction, $\alpha = \tan^{-1}\left(\frac{2kq}{2kq}\right)$

$= \tan^{-1}(1) = \mathbf{45^\circ}$

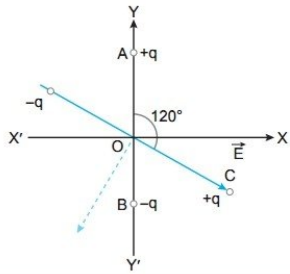
So, E_{net} along 45° from E_1 or E_2.

Q. 4. Two small identical electric dipoles *AB* and *CD*, each of dipole moment $\vec{P}$ are kept at an angle of 120° to each other in an external electric field $\vec{E}$ pointing along the *x*-axis as shown in the figure. Find the

(*a*) dipole moment of the arrangement, and

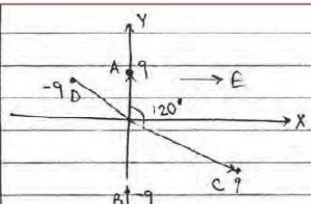
(*b*) magnitude and direction of the net torque acting on it.

[CBSE 2020 (55/2/1)]



Ans.

28



(a) Dipole moment of dipole AB $= \vec{p} = p\hat{j}$.

Dipole moment of dipole CD $= \vec{p} = p\cos 30^\circ\,\hat{i} - p\cos 60^\circ\,\hat{j}$

$= p\frac{\sqrt{3}}{2}\hat{i} - \frac{p}{2}\hat{j}$.

$\therefore$ net dipole moment $(\vec{P}) = p\hat{j} + \left(p\frac{\sqrt{3}}{2}\hat{i} - \frac{p}{2}\hat{j}\right)$

$= p\frac{\sqrt{3}}{2}\hat{i} + \frac{p}{2}\hat{j}$

$\therefore |\vec{P}| = \sqrt{p^2\times\frac{3}{4} + \frac{p^2}{4}} = \sqrt{p^2} = p.$

$\therefore$ magnitude of dipole moment $= p$.

$\tan\theta = \frac{1/2}{\sqrt{3}/2} = \frac{1}{\sqrt{3}}$. $\therefore$ angle made by it with +ve x-axis $= 30^\circ$ (Ans i)

Torque acting on a dipole of dipole moment $\vec{p}$ in electric field $\vec{E}$ $= \vec{p}\times\vec{E}$.

For AB, dipole moment $= p\hat{j}$.

field $= E\hat{i}$

$\therefore$ torque, $\vec{\tau}_{AB} = (p\hat{j}\times E\hat{i}) = pE(-\hat{k})$.

For CD, dipole moment $= \left(\frac{p\sqrt{3}}{2}\hat{i} - \frac{p}{2}\hat{j}\right)$

field $= E\hat{i}$

$\therefore$ Torque, $\vec{\tau}_{CD} = \left(\frac{p\sqrt{3}}{2}\hat{i} - \frac{p}{2}\hat{j}\right) \times E\hat{i}$

$= pE\frac{\sqrt{3}}{2} \times 0 - \frac{p}{2}E.(-\hat{k}) = \frac{pE}{2}\hat{k}$.

net torque $= \vec{\tau}_{AB} + \vec{\tau}_{CD} = -\frac{pE}{2}\hat{k} = \frac{pE}{2}(-\hat{k})$

$\therefore$ magnitude $= \frac{pE}{2}$,

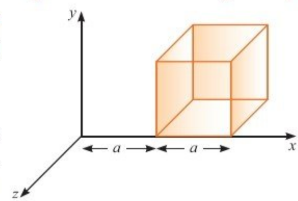
direction = into the plane of paper ~~$(-\hat{k})$~~.

[*Topper's Answer 2020*]

Q. 5. State Gauss's law in electrostatics. A cube with each side '*a*' is kept in an electric field given by $\vec{E} = C \times \hat{r}$, (as is shown in the figure) where *C* is a positive dimensional constant. Find out **[*CBSE (F) 2012*]**

(*i*) the electric flux through the cube, and

(*ii*) the net charge inside the cube.



Ans. Gauss's Law in electrostatics states that the total electric flux through a closed surface enclosing a charge is equal to $\frac{1}{\varepsilon_0}$ times the magnitude of that charge.

$$\phi = \oint_S \vec{E}.d\vec{S} = \frac{q}{\varepsilon_0}$$

(*i*) Net flux, $\phi = \phi_1 + \phi_2$

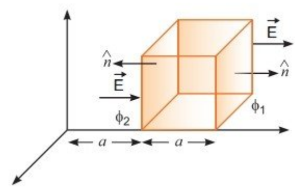
where $\phi_1 = \vec{E}.d\vec{S}$

$= 2aC\, dS \cos 0°$

$= 2aC \times a^2 = 2a^3 C$

$\phi_2 = aC \times a^2 \cos 180° = -a^3C$

$\therefore \quad \phi = 2a^3C + (-a^3C) = \mathbf{a^3C\ Nm^2\ C^{-1}}$



(*ii*) Net charge $(q) = \varepsilon_0 \times \phi = a^3C\,\varepsilon_0$ coulomb

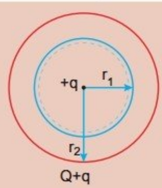
$\therefore \quad q = \mathbf{a^3C\,\varepsilon_0}$ **coulomb.**

Q. 6. A spherical conducting shell of inner radius r_1 and outer radius r_2 has a charge *Q*.

(*a*) A charge *q* is placed at the centre of the shell. Find out the surface charge density on the inner and outer surfaces of the shell.

(*b*) Is the electric field inside a cavity (with no charge) zero; independent of the fact whether the shell is spherical or not? Explain. **[*CBSE 2019 (55/2/1)*]**

Ans. (*a*) Diagram ½



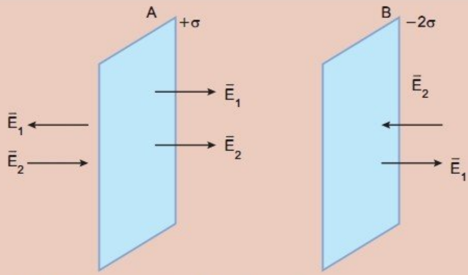
The Surface charge density on inner surface of the shell is $\sigma_1 = -\frac{q}{4\pi r_1^2}$ 1

The surface charge density on outer shell is $\sigma_2 = \frac{Q+q}{4\pi r_2^2}$ ½ (*b*) Consider a Gaussian surface inside the shell, net flux is zero since $q_{net} = 0$. According to Gauss's law it is independent of shape and size of shell. **1**

[*CBSE Marking Scheme 2019 (55/2/1)*]

Q. 7. Two large charged plane sheets of charge densities σ and –2σ C/m² are arranged vertically with a separation of *d* between them. Deduce expressions for the electric field at points (*i*) to the left of the first sheet, (*ii*) to the right of the second sheet, and (*iii*) between the two sheets. [*CBSE 2019 (55/2/1)*]

Ans.



1½

(*i*) Electric field in the region left of first sheet, **½**

$$E_1 = E_1 + E_2$$

$$E_1 = \frac{\sigma}{\varepsilon_0} - \frac{\sigma}{2\varepsilon_0}$$

$$E_1 = +\frac{\sigma}{2\varepsilon_0}$$

It is towards right.

(*ii*) Electric field in the region to the right of second sheet **½**

$$E_{II} = \frac{\sigma}{2\varepsilon_0} - \frac{\sigma}{\varepsilon_0}$$

$$E_{II} = \frac{\sigma}{2\varepsilon_0}$$

It is towards left.

(*iii*) Electric field between the two sheets, **½**

$$E_{III} = E_1 + E_2$$

$$E_{III} = \frac{\sigma}{\varepsilon_0} - \frac{\sigma}{2\varepsilon_0}$$

$$E_{III} = \frac{3\sigma}{2\varepsilon_0}$$

Electric field is towards the right.

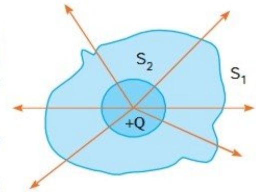
[*CBSE Marking Scheme 2019 (55/2/1)*]

Q.8. (*a*) "The outward electric flux due to charge +*Q* is independent of the shape and size of the surface which encloses it." Give two reasons to justify this statement.

(*b*) Two identical circular loops '1' and '2' of radius *R* each have linear charge densities –λ and +λ C/m respectively. The loops are placed coaxially with their centres $R\sqrt{3}$ distance apart. Find the magnitude and direction of the net electric field at the centre of loop '1'.

[*CBSE Patna 2015*]

Ans. (*a*) In figure, a charge $+Q$ is enclosed inside the surfaces S_1 and S_2.

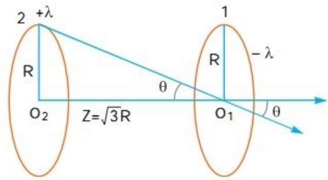


(*i*) For a given charge Q the same number of electric field lines emanating from the surfaces S_1 and S_2 depends on the charge Q and independent to the shape and size of the surfaces of S_1 and S_2.

(*ii*) From Gauss's law the net-outward electric flux through any closed surface of any shape and size is equal to $\frac{1}{\varepsilon_0}$ times the charge enclosed within that surface *i.e.*, $\frac{Q}{\varepsilon_0}$

(*b*) Electric field at the centre O_1 due to loop 1 is given by

$$|\vec{E}_1| = 0 \text{ (As Z = 0)}$$



Electric field at a point outside the loop 2 on the axis passing normally through O_2 of loop 2 is

$$|\vec{E}_2| = \frac{\lambda R}{2\varepsilon_0}\frac{Z}{(R^2+Z^2)^{3/2}}$$

Since $\quad Z = R\sqrt{3}$

$$= \frac{\lambda R}{2\varepsilon_0}\frac{R\sqrt{3}}{(R^2+3R^2)^{3/2}}$$

$$= \frac{\lambda\sqrt{3}}{16\varepsilon_0 R} \text{ towards right (As } \lambda \text{ is positive)}$$

So, net electric field at the centre of loop 1,

$$\vec{E} = \vec{E}_1 + \vec{E}_2$$

$$= 0 + \frac{\lambda\sqrt{3}}{16\varepsilon_0 R} = \boldsymbol{\frac{\lambda\sqrt{3}}{16\varepsilon_0 R}}$$

Q. 9. Two charges q and $-3q$ are placed fixed on x-axis separated by distance 'd'. Where should a third charge $2q$ be placed such that it will not experience any force? **[*NCERT Exemplar*]**

Ans.

Let the charge $2q$ be placed at point P as shown. The force due to q is to the left and that due to $-3q$ is to the right.

$$\therefore \quad \frac{2q^2}{4\pi\varepsilon_0 x^2} = \frac{6q^2}{4\pi\varepsilon_0 (d+x)^2} \Rightarrow (d+x)^2 = 3x^2$$

$$\therefore \quad 2x^2 - 2dx - d^2 = 0 \quad \Rightarrow \quad x = \frac{d}{2} \pm \frac{\sqrt{3}\,d}{2}$$

(–ve sign shows charge $2q$ at p would lie between q and $-3q$ and hence is unacceptable.)

$$\Rightarrow \quad x = \frac{d}{2} + \frac{\sqrt{3}\,d}{2} = \boldsymbol{\frac{d}{2}(1+\sqrt{3})} \text{ to the left of } q.$$

Q. 10. A hollow conducting sphere of inner radius r_1 and outer radius r_2 has a charge Q on its surface. A point charge $-q$ is also placed at the centre of the sphere.

(*a*) What is the surface charge density on the (*i*) inner and (*ii*) outer surface of the sphere?

(*b*) Use Gauss' law of electrostatics to obtain the expression for the electric field at a point lying outside the sphere. **[*CBSE 2020 (55/4/1)*]**

Ans. (*a*) Surface charge density on the inner surface $= \dfrac{q}{4\pi r_1^2}$ ½

On the outer surface $= \dfrac{Q-q}{4\pi r_2^2}$ ½

(*b*) For a spherical Gaussian surface $x > r_2$, 1

$$\int \overrightarrow{E}.\overrightarrow{ds} = \frac{Q-q}{\varepsilon_0}$$

$$E \times 4\pi x^2 = \frac{Q-q}{\varepsilon_0} \quad ½$$

$$E = \frac{1}{4\pi\varepsilon_0}\frac{Q-q}{x^2} \quad ½$$

[CBSE Marking Scheme 2020 (55/4/1)]

Long Answer Questions

Each of the following questions are of 5 marks.

Q. 1. (*i*) State Coulomb's law in electrostatics and write it in vector form, for two charges.

(*ii*) Gauss's law is based on the inverse-square dependence on distance contained in the Coulomb's law.' Explain.

(*iii*) Two charges *A* (charge *q*) and *B* (charge 2*q*) are located at points (0, 0) and (*a*, *a*) respectively. Let $\hat{i}$ and $\hat{j}$ be the unit vectors along *x*-axis and *y*-axis respectively. Find the force exerted by *A* on *B*, in terms of $\hat{i}$ and $\hat{j}$. *[CBSE 2023 (55/1/1)]*

Ans. (*i*) **Coulomb's Law:**

It states that the force of attraction or repulsion between two point charges is directly proportional to the product of magnitude of charges and inversely proportional to the square of distance between them. The direction of this force is along the line joining the two charges, *i.e.*,

$$F = k\frac{q_1 q_2}{r^2}$$

where $k = \dfrac{1}{4\pi\varepsilon}$ is constant of proportionality; ε is permittivity of medium between the charges. If ε_0 is permittivity of free space and K the dielectric constant of medium, then $\varepsilon = K\varepsilon_0$

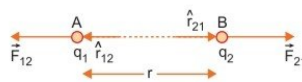
$$F = \frac{1}{4\pi\varepsilon_0 K}\frac{q_1 q_2}{r^2}$$

For free space $K = 1$, Therefore

$$\therefore \qquad F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

In Vector from,

$$\vec{F}_{21} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{r}_{21}$$



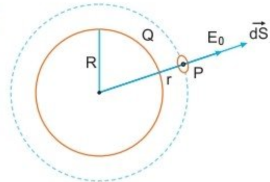
But
$$\hat{r}_{21} = \frac{\vec{r}_{21}}{r}$$

$$\vec{F}_{21} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\frac{\vec{r}_{21}}{r} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^3}\vec{r}_{21}$$

Similarly if $\vec{r}_{12}$ is position vector of q_1 relative to q_2 and $\hat{r}_{12}$ is unit vector from B to A, then

$$\vec{F}_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{r}_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^3}\vec{r}_{12}$$

(*ii*) Let $+\,q$ charge is placed at a point O and a point P lies at distance r from the point O. Imagine a sphere of radius r and centre O. Thus, point P lies on the surface of the sphere. Now, the surface of the sphere will behave as gaussian surface. Therefore, the intensity of electric field on the surface at all the points will be equal in magnitude and will be directed radially outward.



$\therefore$ The electric flux passing through the spherical surface,

$$\phi_E = E\,.\,S\cos 0°$$

$$\phi_E = E\,.\,S \qquad [S = 4\pi r^2]$$

$$\therefore \qquad \phi_E = \pi r^2 E \qquad ...(i)$$

From Gauss's law, $\phi_E = \dfrac{q_{in}}{\varepsilon_0}$ ...(*ii*)

From equation (*i*) and (*ii*), $4\pi r^2 E = \dfrac{q_{in}}{\varepsilon_0}$

or $$E = \frac{q_{in}}{4\pi\varepsilon_0 r^2}$$

Now, imagine a charge q_0 placed at point P.

$\therefore$ Force on q_0, $F = q_0 E$

$$\Rightarrow \qquad F = \frac{q_0 q_{in}}{4\pi\varepsilon_0 r^2}$$

$$\therefore \qquad F = \frac{1}{4\pi\varepsilon_0}.\frac{q_0 q_{in}}{r^2}$$

Hence it verify coulomb's inverse square law.

(*iii*) Force exerted by A on B,

$$\vec{F}_{BA} = \frac{kq_1 q_2}{r^2}\hat{r}$$

Using distance Formula,

$$r = \sqrt{(a-0)^2 + (a-0)^2} = \sqrt{2}\,a$$

$$\hat{r} = \frac{a\hat{i} + a\hat{j}}{\sqrt{2}\,a} = \frac{\hat{i} + \hat{j}}{\sqrt{2}}$$

Now, $$\vec{F}_{BA} = \frac{kq \times 2q}{(\sqrt{2}a)^2}\left(\frac{\hat{i} + \hat{j}}{\sqrt{2}}\right) = \frac{\boldsymbol{kq^2}}{\sqrt{\boldsymbol{2}}\boldsymbol{a^2}}(\hat{\boldsymbol{i}} + \hat{\boldsymbol{j}})\ \textbf{N}$$

Q. 2. Find expressions for the force and torque on an electric dipole kept in a uniform electric field.
[CBSE (AI) 2014; 2019 (55/5/1); 2020 (55/3/1); 2020 (55/5/1); CBSE Sample Paper 2021]

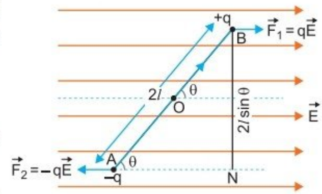
OR

(*i*) Define torque acting on a dipole of dipole moment $\vec{p}$ placed in a uniform electric field $\vec{E}$. Express it in the vector form and point out the direction along which it acts.

(*ii*) What happens if the field is non-uniform?

(*iii*) What would happen if the external field $\vec{E}$ is increasing (*i*) parallel to $\vec{p}$ and (*ii*) anti-parallel to $\vec{p}$? ***[CBSE (F) 2016]***

Ans. Consider an electric dipole placed in a uniform electric field of strength E in such a way that its dipole moment $\vec{p}$ makes an angle θ with the direction of $\vec{E}$. The charges of dipole are $-q$ and $+q$ at separation $2l$ the dipole moment of electric dipole,



$$p = q2l \qquad ...(i)$$

Force: The force on charge $+q$ is, $\vec{F}_1 = q\vec{E}$, along the direction of field $\vec{E}$.

The force on charge $-q$ is $\vec{F}_2 = q\vec{E}$, opposite to the direction of field $\vec{E}$.

Obviously forces $\vec{F}_1$ and $\vec{F}_2$ are equal in magnitude but opposite in direction; hence net force on electric dipole in uniform electric field is

$$F = F_1 - F_2 = qE - qE = 0 \text{ (zero)}$$

As net force on electric dipole is zero, so dipole does not undergo any translatory motion.

Torque: The forces $\vec{F}_1$ and $\vec{F}_2$ form a couple (or torque) which tends to rotate and align the dipole along the direction of electric field. This couple is called the torque and is denoted by τ.

$\therefore$ Torque τ = magnitude of one force × perpendicular distance between lines of action of forces

$$= qE\,(BN)$$
$$= qE\,(2l \sin\theta)$$
$$= (q2l)\,E \sin\theta$$
$$= pE \sin\theta \quad \text{[using (i)]} \qquad ...(ii)$$

Clearly, the magnitude of torque depends on orientation (θ) of the electric dipole relative to electric field. Torque (τ) is a vector quantity whose direction is perpendicular to the plane containing $\vec{p}$ and $\vec{E}$ given by right hand screw rule.

In vector form, $\vec{\tau} = \vec{p} \times \vec{E}$ ...(iii)

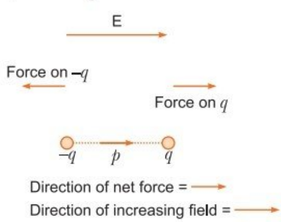
Thus, if an electric dipole is placed in an electric field in oblique orientation, it experiences no force but experiences a torque. The torque tends to align the dipole moment along the direction of electric field.

When the field is non-uniform, the net force will evidently be non-zero. There will be translatory motion of the dipole.

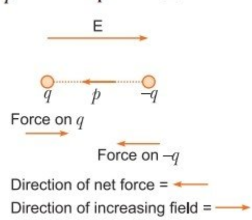
When $\vec{E}$ is parallel to $\vec{p}$, the dipole has a net force in the direction of increasing field.

When $\vec{E}$ is anti-parallel to $\vec{p}$, the net force on the dipole is in the direction of decreasing field.

In general, force depends on the orientation of $\vec{p}$ with respect to $\vec{E}$.



E parallel to p



E antiparallel to p

Q. 3. Find an expression for the electric field strength at a distant point situated (*i*) on the axis and (*ii*) along the equatorial line of an electric dipole. **[*CBSE (AI) 2013; (F) 2015; 2019 (55/5/1)*]**

OR

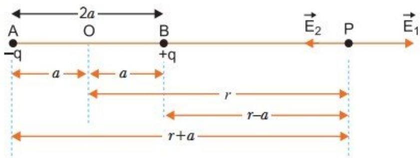
Derive an expression for the electric field intensity at a point on the equatorial line of an electric dipole of dipole moment $\vec{p}$ and length $2a$. What is the direction of this field?

[*CBSE South 2016; 2019 (55/1/1)*] [*CBSE 2023 (55/1/1)*]

Ans. Consider an electric dipole AB. The charges $-q$ and $+q$ of dipole are situated at A and B respectively as shown in the figure. The separation between the charges is $2a$.

Electric dipole moment, $p = q.2a$

The direction of dipole moment is from $-q$ to $+q$.



(*i*) **At axial or end-on position:** Consider a point P on the axis of dipole at a distance r from mid-point O of electric dipole.

The distance of point P from charge $+q$ at B is $BP = r - a$

and distance of point P from charge $-q$ at A is, $AP = r + a$.

Let E_1 and E_2 be the electric field strengths at point P due to charges $+q$ and $-q$ respectively. We know that the direction of electric field due to a point charge is away from positive charge and towards the negative charge. Therefore,

$$E_1 = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r-a)^2} \text{ (from } B \text{ to } P) \text{ and } E_2 = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r+a)^2} \text{ (from } P \text{ to } A)$$

Clearly the directions of electric field strengths $\vec{E}_1$ are $\vec{E}_2$ along the same line but opposite to each other and $E_1 > E_2$ because positive charge is nearer.

$\therefore$ The resultant electric field due to electric dipole has magnitude equal to the difference of E_1 and E_2 direction from B to P *i.e.*

$$E = E_1 - E_2 = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r-a)^2} - \frac{1}{4\pi\varepsilon_0}\frac{q}{(r+a)^2}$$

$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{(r-a)^2} - \frac{1}{(r+a)^2}\right] = \frac{q}{4\pi\varepsilon_0}\left[\frac{(r+a)^2-(r-a)^2}{(r-a)^2(r+a)^2}\right]$$

$$= \frac{q}{4\pi\varepsilon_0}\frac{4ra}{(r^2-a^2)^2} = \frac{1}{4\pi\varepsilon_0}\frac{2(q2a)r}{(r^2-a^2)^2}$$

But $q.2\,a = p$ (electric dipole moment)

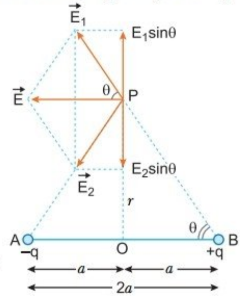
$$\therefore \qquad E = \frac{1}{4\pi\varepsilon_0}\frac{2pr}{(r^2-a^2)^2} \qquad ...(i)$$

If the dipole is infinitely small and point P is far away from the dipole, then $r >> a$, therefore equation (*i*) may be expressed as

$$E = \frac{1}{4\pi\varepsilon_0}\frac{2pr}{r^4} \quad \text{or} \quad E = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3} \qquad ..(ii)$$

This is the expression for the electric field strength at axial position due to a short electric dipole.

(*ii*) **At a point of equatorial line:** Consider a point P on broad side on the position of dipole formed of charges $+q$ and $-q$ at separation $2a$. The distance of point P from mid point (O) of electric dipole is r. Let $\vec{E}_1$ and $\vec{E}_2$ be the electric field strengths due to charges $+q$ and $-q$ of electric dipole.



From fig. $AP = BP = \sqrt{r^2 + a^2}$

$$\therefore \quad \vec{E}_1 = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2 + a^2} \text{ along } B \text{ to } P$$

$$\vec{E}_2 = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2 + a^2} \text{ along } P \text{ to } A$$

Clearly $\vec{E}_1$ and $\vec{E}_2$ are equal in magnitude

i.e., $|\vec{E}_1| = |\vec{E}_2|$ or $E_1 = E_2$.

To find the resultant of $\vec{E}_1$ and $\vec{E}_2$, we resolve them into rectangular components.

Component of $\vec{E}_1$ parallel to $AB = E_1 \cos\theta$, in the direction to $\overrightarrow{BA}$

Component of $\vec{E}_1$ perpendicular to $AB = E_1 \sin\theta$ along OP

Component of $\vec{E}_2$ parallel to $AB = E_2 \cos\theta$ in the direction $\overrightarrow{BA}$

Component of $\vec{E}_2$ perpendicular to $AB = E_2 \sin\theta$ along PO

Clearly, components of $\vec{E}_1$ and $\vec{E}_2$ perpendicular to AB: $E_1 \sin\theta$ and $E_2 \sin\theta$ being equal and opposite cancel each other, while the components of $\vec{E}_1$ and $\vec{E}_2$ parallel to AB : $E_1 \cos\theta$ and $E_2 \cos\theta$, being in the same direction add up and give the resultant electric field whose direction is parallel to $\overrightarrow{BA}$.

$\therefore$ Resultant electric field at P is $E = E_1 \cos\theta + E_2 \cos\theta$

But $E_1 = E_2 = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{(r^2 + a^2)}$

From the figure, $\cos\theta = \dfrac{OB}{PB} = \dfrac{a}{\sqrt{r^2 + a^2}} = \dfrac{a}{(r^2 + a^2)^{1/2}}$

$$E = 2E_1 \cos\theta = 2 \times \frac{1}{4\pi\varepsilon_0}\frac{q}{(r^2 + a^2)}\cdot\frac{a}{(r^2 + a^2)^{1/2}} = \frac{1}{4\pi\varepsilon_0}\frac{2qa}{(r^2 + a^2)^{3/2}}$$

But $q.2a = p$ = electric dipole moment ...(*iii*)

$$\therefore \quad E = \frac{1}{4\pi\varepsilon_0}\frac{p}{(r^2 + a^2)^{3/2}}$$

If dipole is infinitesimal and point P is far away, we have $a << r$, so a^2 may be neglected as compared to r^2 and so equation (*iii*) gives

$$E = \frac{1}{4\pi\varepsilon_0}\frac{p}{(r^2)^{3/2}} = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}$$

i.e., electric field strength due to a short dipole at broadside on position

$$E = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3} \text{ in the direction parallel to } \overrightarrow{BA} \qquad ...(iv)$$

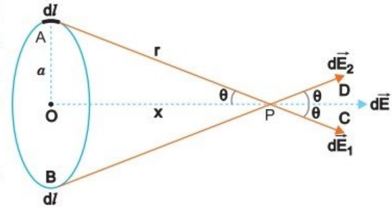
Its direction is parallel to the axis of dipole from positive to negative charge.

It may be noted clearly from equations (ii) and (iv) that electric field strength due to a short dipole at any point is inversely proportional to the cube of its distance from the dipole and the electric field strength at axial position is twice that at broad-side on position for the same distance.

Important: Note the important point that the electric field due to a dipole at large distances falls off as $\dfrac{1}{r^3}$ and not as $\dfrac{1}{r^2}$ as in the case of a point charge.

Q. 4. A charge is distributed uniformly over a ring of radius 'a'. Obtain an expression for the electric intensity E at a point on the axis of the ring. Hence show that for points at large distances from the ring, it behaves like a point charge. **[*CBSE Delhi 2016, 2020 (55/5/1)*]**

Ans. Consider a point P on the axis of uniformly charged ring at a distance x from its centre O. Point P is at distance $r = \sqrt{a^2 + x^2}$ from each element dl of ring. If q is total charge on ring, then, charge per metre length, $\lambda = \frac{q}{2\pi a}$.



The ring may be supposed to be formed of a large number of ring elements.

Consider an element of length dl situated at A.

The charge on element, $dq = \lambda\, dl$

$\therefore$ The electric field at P due to this element

$$d\vec{E}_1 = \frac{1}{4\pi\varepsilon_0}\frac{dq}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{\lambda dl}{r^2}, \text{ along } \overrightarrow{PC}$$

The electric field strength due to opposite symmetrical element of length dl at B is

$$d\vec{E}_2 = \frac{1}{4\pi\varepsilon_0}\frac{dq}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{\lambda dl}{r^2}, \text{ along } \overrightarrow{PD}$$

If we resolve $d\vec{E_1}$ and $d\vec{E_2}$ along the axis and perpendicular to axis, we note that the components perpendicular to axis are oppositely directed and so get cancelled, while those along the axis are added up. Hence, due to symmetry of the ring, the electric field strength is directed along the axis. The electric field strength due to charge element of length dl, situated at A, along the axis will be

$$dE = dE_1 \cos\theta = \frac{1}{4\pi\varepsilon_0}\frac{\lambda dl}{r^2}\cos\theta$$

But, $\cos\theta = \frac{x}{r}$

$\therefore$ $dE = \frac{1}{4\pi\varepsilon_0}\frac{\lambda dl x}{r^3} = \frac{1}{4\pi\varepsilon_0}\frac{\lambda x}{r^3}\, dl$

The resultant electric field along the axis will be obtained by adding fields due to all elements of the ring, *i.e.*,

$\therefore$ $E = \int \frac{1}{4\pi\varepsilon_0}\frac{\lambda x}{r^3} dl = \frac{1}{4\pi\varepsilon_0}\frac{\lambda x}{r^3}\int dl$

But, $\int dl$ = whole length of ring $= 2\pi a$ and $r = (a^2 + x^2)^{1/2}$

$\therefore$ $E = \frac{1}{4\pi\varepsilon_0}\frac{\lambda x}{(a^2+x^2)^{3/2}} 2\pi a$

As, $\lambda = \frac{q}{2\pi a}$, we have $E = \frac{1}{4\pi\varepsilon_0}\frac{\left(\frac{q}{2\pi a}\right)x}{(a^2+x^2)^{3/2}} 2\pi a$

or, $E = \frac{1}{4\pi\varepsilon_0}\frac{qx}{(a^2+x^2)^{3/2}}$, along the axis

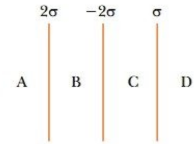
At large distances *i.e.*, $x >> a$, $E = \frac{1}{4\pi\varepsilon_0}\frac{q}{x^2}$,

i.e., the electric field due to a point charge at a distance x.

For points on the axis at distances much larger than the radius of ring, the ring behaves like a point charge.

Q. 5. **(a) State Gauss's law in electrostatics. Show with help of suitable figure that outward flux due to a point charge Q, in vacuum within gaussian surface, is independent of its size and shape.**

(b) In the figure there are three infinite long thin sheets having surface charge density $+2\sigma$, -2σ and $+\sigma$ respectively. Give the magnitude and direction of electric field at a point to the left of sheet of charge density $+2\sigma$ and to the right of sheet of charge density $+\sigma$. *[CBSE Sample Paper 2021]*



Ans. (a) **Statement:** ***The net-outward normal electric flux through any closed surface of any shape is equal to $1/\varepsilon_0$ times the total charge contained within that surface, i.e.,***

$$\oint_S \vec{E} \cdot d\vec{S} = \frac{1}{\varepsilon_0} \Sigma q$$

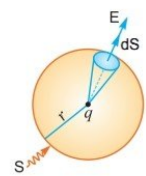
where $\oint_S$ indicates the surface integral over the whole of the closed surface, $\sum q$ is the algebraic sum of all the charges (*i.e.*, net charge in coulombs) enclosed by surface S and remain unchanged with the size and shape of the surface.

Proof: Let a point charge $+q$ be placed at centre O of a sphere S. Then S is a Gaussian surface.

Electric field at any point on S is given by

$$E = \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2}$$

The electric field and area element points radially outwards, so $\theta = 0°$.



Flux through area $d\vec{S}$ is

$$d\phi = \vec{E} \cdot d\vec{S} = E\, dS \cos 0° = E\, dS$$

Total flux through surface S is

$$\phi = \oint_S d\phi = \oint_S E dS = E \oint_S dS = E \times \text{Area of sphere}$$

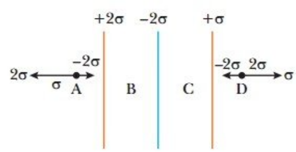
$$\phi = \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2} 4\pi r^2 \quad \text{or,} \quad \boldsymbol{\phi = \frac{q}{\varepsilon_0}} \text{ which proves Gauss's theorem.}$$

(b) At A, both σ and 2σ will act in left and -2σ will act in right, so, charge density at A can be given as

$$E_A = \frac{2\sigma}{2\varepsilon_0} - \frac{2\sigma}{2\varepsilon_0} + \frac{\sigma}{2\varepsilon_0} = \boldsymbol{\frac{\sigma}{2\varepsilon_0}}$$

The net electric field at A is towards left.

Similarly at point D, σ and 2σ will act in right and -2σ will act in left.



So, $$E_D = \frac{\sigma}{2\varepsilon_0} - \frac{2\sigma}{2\varepsilon_0} + \frac{2\sigma}{2\varepsilon_0} = \boldsymbol{\frac{\sigma}{2\varepsilon_0}}$$

The net electric field at D is towards right.

Q. 6. **(i) Using Gauss Theorem show mathematically that for any point outside the shell, the field due to a uniformly charged spherical shell is same as the entire charge on the shell, is concentrated at the centre.** *[CBSE 2019 (55/4/1)]*

(ii) Why do you expect the electric field inside the shell to be zero according to this theorem?

OR *[CBSE Allahabad 2015]*

A thin conducting spherical shell of radius R has charge Q spread uniformly over its surface. Using Gauss's theorem, derive an expression for the electric field at a point outside the shell. *[CBSE Delhi 2009]*

Draw a graph of electric field $E(r)$ with distance r from the centre of the shell for $0 \leq r < \infty$.

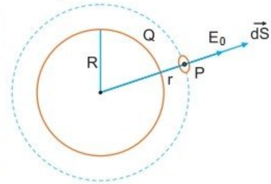
OR

Find the electric field intensity due to a uniformly charged spherical shell at a point (*i*) outside the shell and (*ii*) inside the shell. Plot the graph of electric field with distance from the centre of the shell. *[CBSE North 2016; 2020 (55/1/1)]*

OR

Using Gauss's law obtain the expression for the electric field due to a uniformly charged thin spherical shell of radius *R* at a point outside the shell. Draw a graph showing the variation of electric field with *r*, for *r* > *R* and *r* < *R*. *[CBSE (AI) 2013; 2020 (55/2/1)]*

Ans. (*i*) **Electric field intensity at a point outside a uniformly charged thin spherical shell:** Consider a uniformly charged thin spherical shell of radius R carrying charge Q. To find the electric field outside the shell, we consider a spherical Gaussian surface of radius r ($>R$), concentric with given shell. If $\vec{E}_0$ is electric field outside the shell, then by symmetry electric field strength has same magnitude E_0 on the Gaussian surface and is directed radially outward. Also the directions of normal at each point is radially outward, so angle between $\vec{E}_0$ and $d\vec{S}$ is zero at each point. Hence, electric flux through Gaussian surface. $\phi = \oint_S \vec{E}_0 \cdot d\vec{S}$.



$$\phi = \oint_S \vec{E} \cdot d\vec{S} = \oint_S E_0 dS \cos 0 = E_0 . 4\pi r^2$$

Now, Gaussian surface is outside the given charged shell, so charge enclosed by Gaussian surface is Q.

Hence, by Gauss's theorem

$$\oint_S \vec{E}_0 \cdot d\vec{S} = \frac{1}{\varepsilon_0} \times \text{ charged enclosed}$$

$$\Rightarrow \qquad E_0\, 4\pi r^2 = \frac{1}{\varepsilon_0} \times Q \Rightarrow E_0 = \frac{1}{4\pi\varepsilon_0} \frac{Q}{r^2}$$

Thus, ***electric field outside a charged thin spherical shell is the same as if the whole charge Q is concentrated at the centre.***

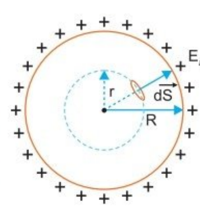
If σ is the surface charge density of the spherical shell, then

$$Q = 4\pi R^2 \sigma \text{ coulomb}$$

$$\therefore \qquad E_0 = \frac{1}{4\pi\varepsilon_0} \frac{4\pi R^2 \sigma}{r^2} = \frac{R^2 \sigma}{\varepsilon_0 r^2}$$

(*ii*) **Electric field inside the shell (hollow charged conducting sphere):**

The charge resides on the surface of a conductor. Thus a hollow charged conductor is equivalent to a charged spherical shell. To find the electric field inside the shell, we consider a spherical Gaussian surface of radius r ($< R$) concentric with the given shell. If $\vec{E}$ is the electric field inside the shell, then by symmetry electric field strength has the same magnitude E_i on the Gaussian surface and is directed radially outward. Also the directions of normal at each point is radially outward, so angle between $\vec{E}_i$ and $d\vec{S}$ is zero at each point. Hence, electric flux through Gaussian surface



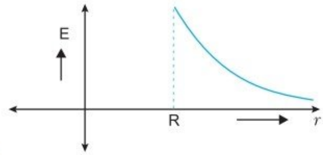
$$= \oint_S \vec{E}_i . d\vec{S} = \oint E_i\, dS \cos 0 = E_i . 4\pi r^2$$

Now, Gaussian surface is inside the given charged shell, so charge enclosed by Gaussian surface is zero.

Hence, by Gauss's theorem

$$\oint_S \vec{E}_i \cdot d\vec{S} = \frac{1}{\varepsilon_0} \times \text{ charge enclosed}$$

$$\Rightarrow \qquad E_i\, 4\pi r^2 = \frac{1}{\varepsilon_0} \times 0 \ \Rightarrow \ E_i = 0$$



Thus, ***electric field at each point inside a charged thin spherical shell is zero. The graph is shown in fig.***

Q. 7. **(*i*) Use Gauss' law to obtain an expression for the electric field due to an infinitely long thin straight wire with uniform linear charge density λ.** ***[CBSE 2020 (55/5/1), 2023 (55/2/1)]***

(*ii*) An infinitely long positively charged straight wire has a linear charge density λ. An electron is revolving in a circle with a constant speed v such that the wire passes through the centre, and is perpendicular to the plane, of the circle. Find the kinetic energy of the electron in terms of magnitudes of its charge and linear charge density λ on the wire.

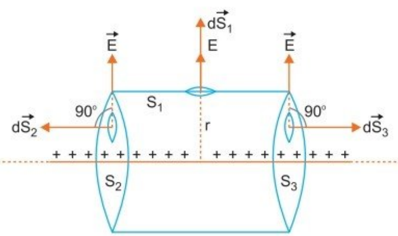
(*iii*) Draw a graph of kinetic energy as a function of linear charge density λ. ***[CBSE 2023 (55/2/1)]***

Ans. (*i*) **Electric field due to infinitely long, thin and uniformly charged straight wire:** Consider an infinitely long line charge having linear charge density λ coulomb metre^{-1} (linear charge density means charge per unit length). To find the electric field strength at a distance r, we consider a cylindrical Gaussian surface of radius r and length l coaxial with line charge. The cylindrical Gaussian surface may be divided into three parts:

(*i*) Curved surface S_1 (*ii*) Flat surface S_2 and (*iii*) Flat surface S_3.

By symmetry, the electric field has the same magnitude E at each point of curved surface S_1 and is directed radially outward.

We consider small elements of surfaces S_1, S_2 and S_3 The surface element vector $d\vec{S}_1$ is directed along the direction of electric field (*i.e.*, angle between $\vec{E}$ and $d\vec{S}_1$ is zero); the elements $d\vec{S}_2$ and $d\vec{S}_3$ are directed perpendicular to field vector $\vec{E}$ (*i.e.*, angle between $d\vec{S}_2$ and $\vec{E}$ is 90° and so also angle between $d\vec{S}_3$ and $\vec{E}$).



Electric Flux through the cylindrical surface

$$\oint_S \vec{E} \cdot d\vec{S} = \int_{S_1} \vec{E} \cdot d\vec{S}_1 + \int_{S_2} \vec{E} \cdot d\vec{S}_2 + \int_{S_3} \vec{E} \cdot d\vec{S}_3$$

$$= \int_{S_1} E\, dS_1 \cos 0° + \int_{S_2} E\, dS_2 \cos 90° + \int_{S_3} E\, dS_3 \cos 90°$$

$$= \int E\, dS_1 + 0 + 0$$

$$= E \int dS_1 \qquad \text{(since electric field } E \text{ is the same at each point of curved surface)}$$

$$= E\, 2\pi r l \qquad \text{(since area of curved surface } = 2\,\pi\, rl)$$

As λ is charge per unit length and length of cylinder is l therefore, charge enclosed by assumed surface = (λl)

$\therefore$ By Gauss's theorem

$$\oint \vec{E} \cdot d\vec{S} = \frac{1}{\varepsilon_0} \times \text{ charge enclosed}$$

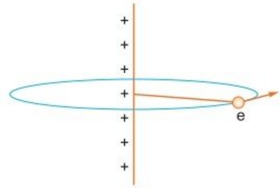
$$\Rightarrow \qquad E\, 2\pi r l = \frac{1}{\varepsilon_0}(\lambda l) \qquad \Rightarrow \qquad \boldsymbol{E = \frac{\lambda}{2\pi\varepsilon_0 r}}$$

Thus, the electric field strength due to a line charge is inversely proportional to r.

(*ii*) Infinitely long charged wire produces a radical electric field.

$$E = \frac{\lambda}{2\pi\varepsilon_0 r} \qquad ...(i)$$

The revolving electron experiences an electrostatic force and provides necessarily centripetal force.

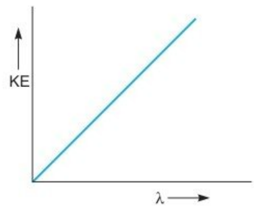


$$eE = \frac{mv^2}{r} \qquad ...(ii)$$

$$\Rightarrow \qquad \frac{e\lambda}{2\pi\varepsilon_0 r} = \frac{mv^2}{r} \quad \Rightarrow \quad mv^2 = \frac{e\lambda}{2\pi\varepsilon_0}$$

Kinetic energy of the electron, $K = \frac{1}{2}mv^2 = \frac{e\lambda}{4\pi\varepsilon_0}$

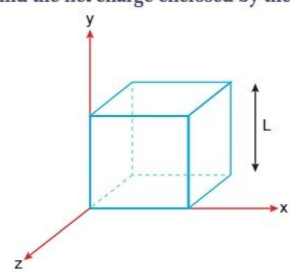
(*iii*)



Q. 8. **(*i*) Define electric flux and write its SI unit.**

(*ii*) Use Gauss law to obtain the expression for the electric field due to a uniformly charged infinite plane sheet.

(*iii*) A cube of side L is kept in space, as shown in the figure. An electric field $\vec{E} = (Ax+B)\hat{i}$ NC^{-1} exists in the region. Find the net charge enclosed by the cube. **[*CBSE 2023 (55/3/1)*]**

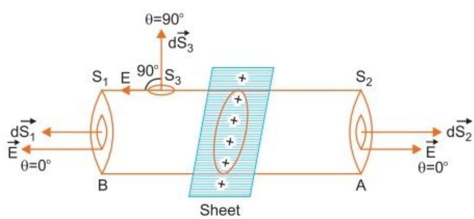


Ans. (*i*) **Electric flux:** It is defined as the total number of electric field lines passing through an area normal to its surface.

Also, $\phi = \oint \vec{E} \cdot d\vec{S}$

The SI unit is Nm^2/C or volt-metre.

(*ii*) Let electric charge be uniformly distributed over the surface of a thin, non-conducting infinite sheet. Let the surface charge density (*i.e.*, charge per unit surface area) be σ. We need to calculate the electric field strength at any point distant r from the sheet of charge.



To calculate the electric field strength near the sheet, we now consider a cylindrical Gaussian surface bounded by two plane faces A and B lying on the opposite sides and parallel to the charged sheet and the cylindrical surface perpendicular to the sheet (fig). By symmetry the electric field strength at every point on the flat surface is the same and its direction is normal outwards at the points on the two plane surfaces and parallel to the curved surface.

Total electric flux

or $$\oint_S \vec{E} \cdot d\vec{S} = \int_{S_1} \vec{E} \cdot d\vec{S}_1 + \int_{S_2} \vec{E} \cdot d\vec{S}_2 + \int_{S_3} \vec{E} \cdot d\vec{S}_3$$

$$\oint_S \vec{E} \cdot d\vec{S} = \int_{S_1} E\, dS_1 \cos 0° + \int_{S_2} E\, dS_2 \cos 0° + \int_{S_3} E\, dS_3 \cos 90°$$

$$= E\int dS_1 + E\int dS_2 = Ea + Ea = 2Ea$$

$\therefore$ Total electric flux $= 2Ea$

As σ is charge per unit area of sheet and a is the intersecting area, the charge enclosed by Gaussian surface $= \sigma a$

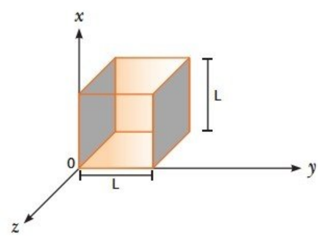
According to Gauss's theorem,

Total electric flux $= \frac{1}{\varepsilon_0} \times$ (total charge enclosed by the surface)

i.e., $$2Ea = \frac{1}{\varepsilon_0}(\sigma a) \qquad \therefore \quad E = \frac{\sigma}{2\varepsilon_0}$$

Thus electric field strength due to an infinite flat sheet of charge is independent of the distance of the point.

(*iii*) Given, $\vec{E} = (Ax + B)\hat{i}$ NC^{-1}



From Gauss's Law, $\oint E.ds = \frac{q_{in}}{\varepsilon_0}$

Only flux through shaded portion will contribute.

Flux through face A, $\phi_A = \vec{E}_A . d\vec{s}$ where, at $x = 0$,) $\vec{E}_A = \left(A(0) + B\right)\hat{i}$

$= B\hat{i} . L^2(-\hat{i})\ \phi_A = -BL^2$

Flux through face B, $\phi_B = \vec{E} . d\vec{s}$ where, at $x = L$, $\vec{E}_B = (AL + B)\hat{i}$

$= (AL + B)\hat{i} . L^2\,\hat{i} = (AL^3 + BL^2)$

Hence, Net flux $= \phi_A + \phi_B = -BL^2 + AL^3 + BL^2$

$= AL^3$

Again, from Gauss theorem, $\phi_{net} = \frac{q_{in}}{\varepsilon_0}$

$\therefore$ $$q_{in} = AL^3\, \varepsilon_0\, \mathbf{C}$$

Q. 9. Apply Gauss's Theorem to find the electric field near a charged conductor.

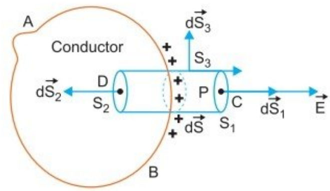
OR

Show that the electric field at the surface of a charged conductor is $\vec{E} = \frac{\sigma}{\varepsilon_0}\hat{n}$ where σ is surface charge density and $\hat{n}$ is a unit vector normal to the surface in the outward direction.

[*CBSE (AI) 2010*]

Ans. Let a charge Q be given to a conductor, this charge under electrostatic equilibrium will redistribute and the electric field inside the conductor is zero (*i.e.*, $E_{in}=0$).

Let us consider a point P at which electric field strength is to be calculated, just outside the surface of the conductor. Let the surface charge density on the surface of the conductor in the neighbourhood of P be σ coulomb/metre^2. Now consider a small cylindrical box CD having one base C passing through P; the other base D lying inside the conductor and the curved surface being perpendicular to the surface of the conductor.



Let the area of each flat base be a. As the surface of the conductor is equipotential surface, the electric field strength **E** at P, just outside the surface of the conductor is perpendicular to the surface of the conductor in the neighbourhood of P.

The flux of electric field through the curved surface of the box is zero, since there is no component of electric field E normal to curved surface. Also the flux of electric field through the base D is zero, as electric field strength inside the conductor is zero. Therefore the resultant flux of electric field through the entire surface of the box is same as the flux through the face C. This may be analytically seen as:

If S_1 and S_2 are flat surfaces at C and D and S_3 is curved surface, then

$$\text{Total electric flux } \oint_S \vec{E}\cdot d\vec{S} = \int_{S_1}\vec{E}\cdot d\vec{S}_1 + \int_{S_2}\vec{E}\cdot d\vec{S}_2 + \int_{S_3}\vec{E}\cdot d\vec{S}_3$$

$$= \int_{S_1} E\, dS_1 \cos 0 + \int_{S_2}\vec{0}\cdot d\vec{S}_2 + \int_{S_3} E\, dS_3 \cos 90°$$

$$\therefore \qquad \oint_S E\, dS_1 = Ea$$

As the charge enclosed by the cylinder is (σa) coulomb, we have, using Gauss's theorem,

$$\text{Total electric flux} = \frac{1}{\varepsilon_0}\times \text{charge enclosed}$$

$$\Rightarrow \qquad Ea = \frac{1}{\varepsilon_0}(\sigma a) \qquad \text{or} \qquad E = \frac{\sigma}{\varepsilon_0}$$

Thus the electric field strength at any point close to the surface of a charged conductor of any shape is equal to $1/\varepsilon_0$ times the surface charge density σ. This is known as Coulomb's law. The electric field strength is directed radially away from the conductor if σ is positive and towards the conductor if σ is negative.

If $\hat{n}$ is unit vector normal to surface in outward direction, then $\vec{E} = \frac{\sigma}{\varepsilon_0}\hat{n}$.

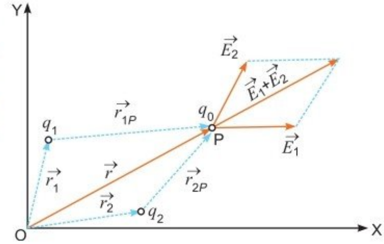
Obviously electric field strength near a plane conductor is twice of the electric field strength near a non-conducting thin sheet of charge.

Q. 10. (*a*) **Consider a system of n charges $q_1, q_2, \ldots q_n$ with position vectors $\vec{r_1}, \vec{r_2}, \vec{r_3}, \ldots, \vec{r_n}$ relative to some origin 'O'. Deduce the expression for the net electric field $\vec{E}$ at a point P with position vector $\vec{r_p}$, due to this system of charges.**

(*b*) **Three point electric charges $+q$ each are kept at the vertices of an equilateral triangle of side a. Determine the magnitude and sign of the charge to be kept at the centroid of the triangle so that the charges at the vertices remain in equilibrium.** **[*CBSE (F) 2015*] [*HOTS*]**

Ans. **(a) Electric field due to a system of point charges.**

Consider a system of N point charges q_1, q_2, ..., q_n, having position vectors $\vec{r}_1, \vec{r}_2, ..., \vec{r}_n$ with respect to origin O. We wish to determine the electric field at point P whose position vector is $\vec{r}$. According to Coulomb's law, the force on charge q_0 due to charge q_1 is



$$\vec{F}_1 = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_0}{r_{2p}^2}\hat{r}_{1P}$$

where $\hat{r}_{1P}$ is a unit vector in the direction from q_1 to P and r_{1P} is the distance between q_1 and P. Hence the electric field at point P due to charge q_1 is

$$\vec{E}_1 = \frac{\vec{F}_1}{q_0} = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r_{1P}^2}\hat{r}_{1P}$$

Similarly, electric field at P due to charge q_2,

$$\vec{E}_2 = \frac{1}{4\pi\varepsilon_0}\frac{q_2}{r_{2P}^2}\hat{r}_{2P}$$

According to the principle of superposition of electric fields, the electric field at any point due to a group of point charges is equal to the vector sum of the electric fields produced by each charge individually at that point, when all other charges are assumed to be absent.

Hence, the electric field at point P due to the system of n charges is

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \ldots + \vec{E}_n$$

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1}{r_{1P}^2}\hat{r}_{1P} + \frac{q_2}{r_{2P}^2}\hat{r}_{2P} + \ldots + \frac{q_n}{r_{nP}^2}\hat{r}_{nP}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n}\frac{q_i}{r_{iP}^2}\hat{r}_{iP}$$

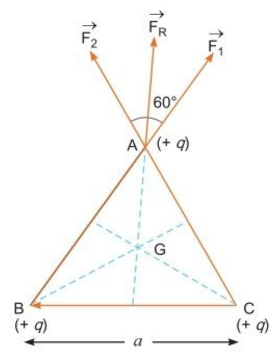
(b) The charge at any vertex will remain in equilibrium if the net force experienced by this charge due to all other three charges is zero.

Let Q be the required charge to be kept at the centroid G.

Considering the charge at A,

Force $\vec{F}_1$ on charge at A due to charge at B

$$\vec{F}_1 = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{a^2} \text{ along } \overrightarrow{BA}$$



Force $\vec{F}_2$ on charge at A due to charge at C

$$\vec{F}_2 = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{a^2} \text{ along } \overrightarrow{CA}$$

Since angle between $\vec{F}_1$ and $\vec{F}_2$ is 60°.

$$\vec{F}_1 + \vec{F}_2 = \sqrt{3}\frac{1}{4\pi\varepsilon_0}\frac{q^2}{a^2} \text{ along } \overrightarrow{GA}$$

Also, the distance of centroid G from any vertex is $\dfrac{a}{\sqrt{3}}$.

The nature of charge to be kept at G has to be opposite (–ve) so that it exerts a force of attraction on charge ($+q$) kept at A to balance the force $\vec{F}_1 + \vec{F}_2$.

Force exerted by ($-Q$) kept at G on charge ($+q$) at $A = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{\left(\frac{a}{\sqrt{3}}\right)^2} = \frac{1}{4\pi\varepsilon_0}\frac{Q.3q}{a^2}$ along $\overrightarrow{AG}$

Equating the two forces, being equal and opposite

$$\sqrt{3}\frac{1}{4\pi\varepsilon_0}\frac{q^2}{a^2} = -\frac{1}{4\pi\varepsilon_0}\frac{3Qq}{a^2} \quad \Rightarrow \quad Q = -\frac{q}{\sqrt{3}}$$

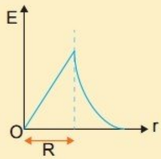
Questions for Practice

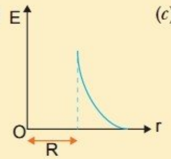
1. **Choose and write the correct option in the following questions.**

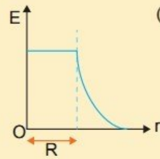
   (*i*) Two point charges $+8q$ and $-2q$ are located at $x = 0$ and $x = L$ respectively. The point on x axis at which net electric field is zero due to these charges is **[*CBSE Sample Paper-2022, Term-1)*]**

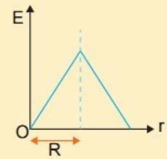
   (*a*) $8L$ (*b*) $4L$ (*c*) $2L$ (*d*) L

   (*ii*) Which one of the following plots represents the variation of electric field with distance r due to a thin spherical shell of radius R? (r is measured from the centre of the spherical shell)

   (*a*)


   (*b*)


   (*c*)


   (*d*)


   (*iii*) An object has charge of 1 C and gains 5.0×10^{18} electrons. The net charge on the object becomes **[*CBSE 2022 (55/2/4), Term-1*]**

   (*a*) – 0.80 C (*b*) + 0.80 C (*c*) + 1.80 C (*d*) + 0.20 C

   (*iv*) The electric flux emerging out from 1C charge is **[*CBSE 2020 (55/3/1)*]**

   (*a*) $\frac{1}{\varepsilon_0}$ (*b*) 4π (*c*) $\frac{4\pi}{\varepsilon_0}$ (*d*) ε_0

   (*v*) In which of the following cases the electric field strength is independent of distance? **[*CBSE 2020 (55/3/1)*]**

   (*a*) Due to a point charge (*b*) Due to a line charge

   (*c*) Due to a spherical charge (*d*) Due to infinite flat sheet of charge

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

   (*a*) ***Both A and R are true and R is the correct explanation of A.***

   (*b*) ***Both A and R are true but R is not the correct explanation of A.***

   (*c*) ***A is true but R is false.***

   (*d*) ***A is false and R is also false.***

   (*i*) **Assertion (*A*) :** If a proton and an electron a replaced in the same uniform electric field, they experience different acceleration.

   Reason (*R*) : Electric force on a test charge is independent of its mass.

(*ii*) **Assertion (*A*) :** The charge given to a metallic sphere does not depend on whether it is hollow or solid.

Reason (*R*) : Since the charge resides only on the surface of the conductor.

3. Two insulated charged copper spheres *A* and *B* of identical size have charges q_A and $-3q_A$ respectively. When they are brought in contact with each other and then separated, what are the new charges on them?

4. Two charges of magnitudes $-3Q$ and $+2Q$ are located at points $(a, 0)$ and $(4a, 0)$ respectively. What is the electric flux due to these charges through a sphere of radius '$5a$' with its centre at the origin?

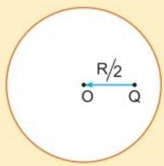
5. A charge Q μC is placed at the centre of a cube. What is the electric flux coming out from any one surface? **[*CBSE (AI) 2012*]**

6. Two identical point charges, q each, are kept 2 m apart in air. A third point charge Q of unknown magnitude and sign is placed on the line joining the charges such that the system remains in equilibrium. Find the position and nature of Q.

7. Draw the pattern of electric field lines, when a point charge $-Q$ is kept near an uncharged conducting plate. **[*CBSE 2019 (55/1/1)*]**

8. A charge q is placed at the centre of a cube of side l. What is the electric flux passing through two opposite faces of the cube? **[*CBSE (AI) 2012*]**

9. Figure shows a point charge $+Q$, located at a distance $\frac{R}{2}$ from the centre of a spherical metal shell. Draw the electric field lines for the given system. **[*CBSE Sample Paper 2016*]**



10. An electric dipole is held in a uniform electric field.
    (*i*) Show that the net force acting on it is zero.
    (*ii*) The dipole is aligned parallel to the field. Find the work done in rotating it through the angle of 180°. **[*CBSE (AI) 2012*]**

11. Two concentric metallic spherical shells of radii R and $2R$ are given charges Q_1 and Q_2 respectively. The surface charge densities on the outer surfaces of the shells are equal. Determine the ratio $Q_1 : Q_2$. **[*CBSE (F) 2013*]**

12. Consider a uniform electric field $\vec{E} = 3\times10^3\hat{i}\ \text{NC}^{-1}$. (*a*) What is the flux of this field through a square of 10 cm on a side whose plane is parallel to the *yz* plane? (*b*) What is the flux through the same square if the normal to its plane makes a 60° angle with the *x*-axis? **[*NCERT*]**

13. Two large, thin metal plates are parallel and close to each other. On their inner faces, the plates have surface charge densities of opposite signs and of magnitude 17.0×10^{-22} C/m^2 What is electric field strength E: (*a*) in the outer region of the first plate, (*b*) in the outer region of the second plate, and (*c*) between the plates? **[*NCERT*]**

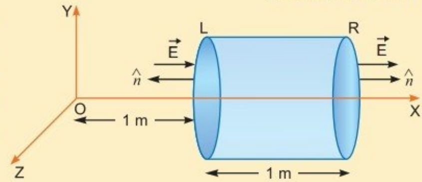
14. A long charged cylinder of linear charge density $+\lambda_1$ is surrounded by a hollow coaxial conducting cylinder of linear charge density $-\lambda_2$. Use Gauss's law to obtain expressions for the electric field at a point (*i*) in the space between the cylinders, and (*ii*) outside the larger cylinder.

15. Four point charges $q_A = 2\ \mu$C, $q_B = -5\mu$C, $q_C = 2\ \mu$C and $q_D = -5\ \mu$C are located at the corners of a square *ABCD* of side 10 cm. What is the force on a charge of 1 μC placed at the centre of the sphere? **[*NCERT*]**

16. Two large charged plane sheets of charge densities σ and -2σ C/m^2 are arranged vertically with a separation of d between them. Deduce expressions for the electric field at points (*i*) to the left of the first sheet, (*ii*) to the right of the second sheet, and (*iii*) between the two sheets.

17. A spherical conducting shell of inner radius r_1 and outer radius r_2 has a charge 'Q'. A charge 'q' is placed at the centre of the shell.
    (*a*) What is the surface charge density on the (*i*) inner surface, (*ii*) outer surface of the shell?
    (*b*) Write the expression for the electric field at a point $x > r_2$ from the centre of the shell.
    [*CBSE (AI) 2010*]

18. A hollow cylindrical box of length 1 m and area of cross-section 25 cm^2 is placed in a three dimensional coordinate system as shown in the figure. The electric field in the region is given by $\vec{E} = 50\,x\,\hat{i}$, where E is in NC^{-1} and x is in metres. Find



    (*i*) net flux through the cylinder.
    (*ii*) charge enclosed by the cylinder. **[*CBSE Delhi 2013*]**

19. Two parallel uniformly charged infinite plane sheets, '1' and '2', have charge densities $+\sigma$ and -2σ respectively. Give the magnitude and direction of the net electric field at a point
    (*i*) in between the two sheets and (*ii*) outside near the sheet '1'. **[*CBSE Ajmer 2015*]**

20. The electric field E due to any point charge near it is defined as $E = \lim_{q \to 0} \frac{F}{q}$ where q is the test charge and F is the force acting on it. What is the physical significance of $\lim_{q \to 0}$ in this expression? Draw the electric field lines of point charge Q when (*i*) $Q > 0$ and (*ii*) $Q < 0$.

21. Two point charges of $+5 \times 10^{-19}$ C and $+20 \times 10^{-19}$ C are separated by a distance of 2 m. Find the point on the line joining them at which electric field intensity is zero.

22. Two charges of value 2 μC and –50 μC are placed 80 cm apart. Calculate the distance of the point from the smaller charge where the intensity is zero.

Answers

1. (*i*) (*c*) (*ii*) (*b*) (*iii*) (*d*) (*iv*) (*a*) (*v*) (*d*)

2. (*i*) (*b*) (*ii*) (*a*)

3. $-q_A, -q_A$ **4.** $\frac{-Q}{\varepsilon_0}$ **5.** $\frac{Q}{6\varepsilon_0}$ μVm **6.** 1 m **8.** $\frac{q}{3\varepsilon_0}$ Vm

10. (*ii*) $2pE$ **11.** 1 : 4 **12.** (*a*) 30 Nm^{2}C^{-1} (*b*) 15 Nm^{2}C^{-1} **13.** (*a*) 0 (*b*) 0 (*c*) 1.92×10^{-10} NC^{-1}

15. 0 **17.** (*a*) (*i*) $\frac{-q}{4\pi r_1^2}$ (*ii*) $\frac{Q+q}{4\pi r_2^2}$ (*b*) $\frac{1}{4\pi\varepsilon_0}\frac{Q+q}{x^2}$

18. (*i*) 0.125 Nm^{2}C^{-1} (*ii*) 1.107×10^{-12}C

19. (*i*) $\frac{-3\sigma}{\varepsilon_0}\hat{j}$ (*ii*) $\frac{-\sigma}{2\varepsilon_0}\hat{j}$

21. $\frac{2}{3}$ m **22.** 0.2 m

2 Electrostatic Potential and Capacitance

POINTS TO REMEMBER

1. Electric Potential

The electric potential is the physical quantity which determines the direction of charge flow between two bodies when brought in contact. The positive charge always flows from a body at higher potential to that at lower potential.

Definition: The electric potential at any point in an electric field is defined as the work done in bringing a unit positive test charge from infinity to that point without acceleration.

If W is the work done in bringing infinitesimal positive test charge q_0 from infinity to given point, then electric potential

$$V = \frac{W}{q_0}$$

Electric potential at any point is also defined as the negative line integral of electric field from infinity to given point (independent of path followed).

i.e., $$V = -\int_{\infty}^{r} \vec{E}.\vec{dl}$$

The unit of electric potential is joule/coulomb or volt and its dimensional formula is $[ML^2 T^{-3} A^{-1}]$.

2. Potential Difference

The potential difference between two points in an electric field is defined as the work done in bringing unit positive charge from one point to another.

3. Formulae for Electric Potential

(*a*) Due to a point charge q at a point distant r is $V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$

(*b*) Due to a short electric dipole at a distance r from its centre

(*i*) at its axis is $V = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^2}$

(*ii*) at its equatorial position, $V = 0$

(*iii*) at a general point having polar coordinates (r, θ) with respect to centre of dipole is

$$V = \frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{r^2}$$

(*c*) due to a system of charges is

$$V = V_1 + V_2 + ... + V_N = \sum_{i=1}^{N}\frac{1}{4\pi\varepsilon_0}\frac{q_i}{r_i} = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1}{r_1} + \frac{q_2}{r_2} + ... + \frac{q_N}{r_N}\right]$$

4. Equipotential Surface

An equipotential surface is the surface having the same potential at each point. The surface of a charged conductor in equilibrium is a equipotential surface.

5. Electric Potential Energy of a System of Point Charges

If q_1 and q_2 are point charges at separation r_{12}, then electric potential energy $U = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}}$.

If there are n point charges $q_1, q_2, ... q_n$ in system at separation r_{ij} between i^{th} and j^{th} charge ($i = 1, 2, ..., n, j = 2, 3, ... n$) then potential energy of system

$$U = \frac{1}{4\pi\varepsilon_0}\sum_{i}^{n}\sum_{j>i}^{n}\frac{q_i q_j}{r_{ij}} \qquad (i = 1, 2,..., n, j=2, 3,...n)$$

6. Electric Potential Energy of a Dipole in Uniform Electric Field

Potential energy of dipole in uniform electric field is

$$U = -pE\cos\theta = -\vec{p}\cdot\vec{E}$$

Work done in rotating the dipole in uniform electric field from inclination θ_1 to θ_2

$$W = U_2 - U_1 = pE(\cos\theta_1 - \cos\theta_2)$$

If dipole is initially in stable equilibrium position ($\theta_1 = 0$) and finally its inclination is θ, then

$$W = pE(1 - \cos\theta)$$

7. Conductors and Insulators

Conductors are those substances which contain free charge carriers and so allow easy flow of current.

Insulators are those substances which contain practically no free charge carriers and do not allow the flow of current.

8. Free and Bound Charges Inside a Conductor

The electrons are free charge carriers inside a metallic conductor while positive ions fixed in lattice are bound charge carriers.

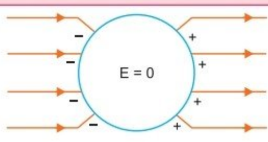
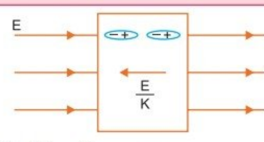
9. Dielectrics and Electric Polarisation

The insulators are often referred as dielectrics. Each dielectric is formed of atoms/molecules. In some dielectrics the positive and negative charge centres coincide, such dielectrics are said to be non-polar dielectrics. While in some other dielectrics the centres of positive and negative charges do not coincide, such dielectrics have permanent electric dipole moment and said to be polar dielectrics. The example of polar dielectric is water, while example of non-polar dielectric is carbon dioxide (CO_2).

When a dielectric is placed in an external electric field, the centres of positive and negative dipoles get separated (in non-polar dielectrics) or get farther away (in polar dielectrics), so that molecules of dielectric gain a permanent electric dipole moment; this process is called polarisation and the dipole is said to be polarised.

The induced dipole moment developed per unit volume in an electric field is called polarisation density. Numerically it is equal to surface charge density induced at the faces which are perpendicular to the direction of applied electric field.

10. The Behaviour of a Conductor and Dielectric in the Presence of External Electric Field.

Conductor	Dielectric
	 where K is dielectric constant
1. No electric field lines travel inside conductor.	1. Alignment of atoms takes place due to electric field.
2. Electric field inside a conductor is zero.	2. This results in a small electric field inside dielectric in opposite direction. Net field inside the dielectric is $\frac{E}{K}$.

11. Capacitor and Capacitance

A capacitor contains two oppositely charged metallic conductors at a finite separation. It is a device by which capacity of storing charge may be varied simply by changing separation and/or medium between the conductors.

The capacitance of a capacitor is defined as the ratio of magnitude of charge (Q) on either plate and potential difference (V) across the plate, *i.e.*,

$$C = \frac{Q}{V}$$

The unit of capacitance is coulomb/volt or farad (F).

12. Combination of Capacitors in Series and Parallel

(a) Series Combination: When capacitors are connected in series, then net capacitance C is given by

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Net charge, $Q = q_1 = q_2 = q_3$ (remain same)

Net potential difference, $V = V_1 + V_2 + V_3$

(b) Parallel Combination: When capacitors are connected in parallel, then the net capacitance

$$C = C_1 + C_2 + C_3$$

In parallel combination net charge, $Q = q_1 + q_2 + q_3$

Net potential difference, $V = V_1 = V_2 = V_3$ (remain same)

13. Capacitance of Parallel Plate Capacitor

A parallel plate capacitor consists of two parallel metallic plates separated by a dielectric. The capacitance is given by

$$C = \frac{K\varepsilon_0 A}{d},$$

where K is dielectric constant, A = area of each plate and d = separation between the plates.

Special Cases:

(*i*) When there is no medium between the plates, then $K = 1$, so

$$C_{vacuum} = \frac{\varepsilon_0 A}{d} = C_0$$

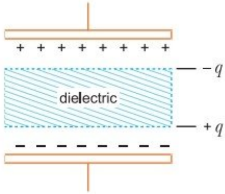
(*ii*) When space between the plates is partly filled with a medium of thickness t and dielectric constant K, then capacitance

$$C = \frac{\varepsilon_0 A}{d - t + \frac{t}{K}} = \frac{\varepsilon_0 A}{d - t\left(1 - \frac{1}{K}\right)}$$

Clearly, $C > C_0$, *i.e.*, on introduction of a dielectric slab between the plates of a parallel plate capacitor, its capacitance increases.

14. Charge Induced on a Dielectric

$q' = -q\left(1 - \frac{1}{K}\right)$ where q is free charge on the capacitor plates.



15. Energy stored in a Charged Capacitor

$$U = \frac{1}{2}CV^2 = \frac{Q^2}{2C} = \frac{1}{2}QV$$

This energy resides in the medium between the plates.

The unit is joule (J) .The energy stored per unit volume of a charged capacitor is given by

$$u = \frac{U}{V} = \frac{1}{2}\varepsilon_0 E^2$$

where E is electric field strength. The unit is joule/m^3 (J/m^3)

POINTS TO REMEMBER

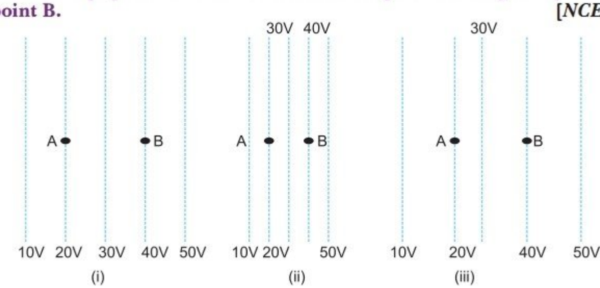
Multiple Choice Questions

Choose and write the correct option(s) in the following questions.

1. **Some charge is being given to a conductor. Then, its potential**
   (*a*) is maximum at surface.
   (*b*) is maximum at centre.
   (*c*) remains the same throughout the conductor.
   (*d*) is maximum somewhere between surface and centre.

2. **A positively charged particle is released from rest in an uniform electric field. The electric potential energy of the charge** [*NCERT Exemplar*]
   (*a*) remains a constant because the electric field is uniform.
   (*b*) increases because the charge moves along the electric field.
   (*c*) decreases because the charge moves along the electric field.
   (*d*) decreases because the charge moves opposite to the electric field.

3. **Figure shows some equipotential lines distributed in space. A charged object is moved from point A to point B.** [*NCERT Exemplar*]

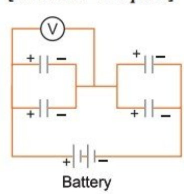


   (*a*) The work done in Fig. (*i*) is the greatest.
   (*b*) The work done in Fig. (*ii*) is least.
   (*c*) The work done is the same in Fig. (*i*), Fig. (*ii*) and Fig. (*iii*).
   (*d*) The work done in Fig. (*iii*) is greater than Fig. (*ii*) but equal to that in Fig. (*i*).

4. **The electrostatic potential on the surface of a charged conducting sphere is 100 V. Two statements are made in this regard:** [*NCERT Exemplar*]
   S_1 : At any point inside the sphere, electric intensity is zero.
   S_2 : At any point inside the sphere, the electrostatic potential is 100 V.
   Which of the following is a correct statement?
   (*a*) S_1 is true but S_2 is false.
   (*b*) Both S_1 and S_2 are false.
   (*c*) S_1 is true, S_2 is also true and S_1 is the cause of S_2.
   (*d*) S_1 is true, S_2 is also true but the statements are independent.

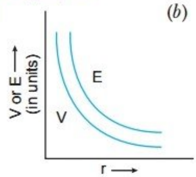
5. **Equipotentials at a great distance from a collection of charges whose total sum is not zero are approximately** [*NCERT Exemplar*]
   (*a*) spheres (*b*) planes
   (*c*) paraboloids (*d*) ellipsoids

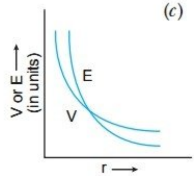
6. **Four capacitors, each 50 μF are connected as shown. The *DC* voltmeter *V* reads 100 V. The charge on each plate of each capacitor is**

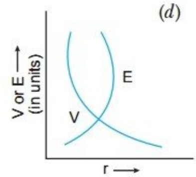


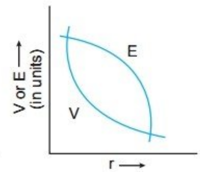
   (*a*) 2×10^{-3} C (*b*) 5×10^{-3} C
   (*c*) 0.2 C (*d*) 0.5 C

7. **The variation potential V with r and electric field E with r for a point charge is correctly shown in the graphs.**

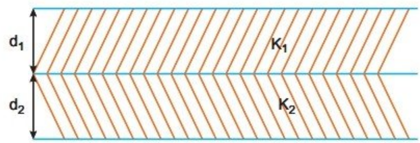
(*a*)


(*b*)


(*c*)


(*d*)


8. **A parallel plate capacitor is made of two dielectric blocks in series. One of the blocks has thickness d_1 and dielectric constant k_1 and the other has thickness d_2 and dielectric constant k_2 as shown in figure. This arrangement can be thought as a dielectric slab of thickness $d\ (= d_1 + d_2)$ and effective dielectric constant k. The k is** **[*NCERT Exemplar*]**



(*a*) $\dfrac{k_1 d_1 + k_2 d_2}{d_1 + d_2}$ (*b*) $\dfrac{k_1 d_1 + k_2 d_2}{k_1 + k_2}$ (*c*) $\dfrac{k_1 k_2 (d_1 + d_2)}{k_1 d_1 + k_2 d_2}$ (*d*) $\dfrac{2k_1 k_2}{k_1 + k_2}$

9. **Equipotential surfaces** **[*NCERT Exemplar*]**

(*a*) are closer in regions of large electric fields compared to regions of lower electric fields.

(*b*) will be more crowded near sharp edges of a conductor.

(*c*) will be more crowded near regions of large charge densities.

(*d*) will always be equally spaced.

10. **A 2 μF capacitor is charged to 200 volt and then the battery is disconnected. When it is connected in parallel to another uncharged capacitor, the potential difference between the plates of both is 40 volt. The capacitance of the other capacitor is**

(*a*) 2 μF (*b*) 4 μF (*c*) 8 μF (*d*) 16 μF

11. ***n* identical capacitors joined in parallel are charged to a common potential *V*. The battery is disconnected. Now, the capacitors are separated and joined in series. For the new combination:**

(*a*) energy and potential difference both will remain unchanged

(*b*) energy will remain same, potential difference will become nV

(*c*) energy and potential both will become n times

(*d*) energy will become n times, potential difference will remain V.

12. **The capacitance of a capacitor becomes $\dfrac{7}{6}$ times its original value if a dielectric slab of thickness $t = \dfrac{2}{3}d$ is introduced in between the plates, where d is the separation between the plates. The dielectric constant of the slab is**

(*a*) $\dfrac{14}{11}$ (*b*) $\dfrac{11}{14}$

(*c*) $\dfrac{7}{11}$ (*d*) $\dfrac{11}{7}$

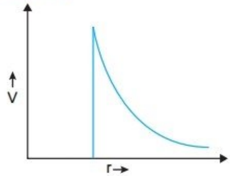
13. **The plates of a parallel plate capacitor are 4 cm apart, the first plate is at 300 V and the second plate at – 100 V. The voltage at 3 cm from the second plate is**

(*a*) 200 V (*b*) 400 V

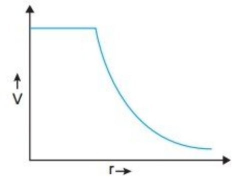
(*c*) 250 V (*d*) 500 V

14. In the case of a charged metallic sphere, potential (V) changes with respect to distance (r) from the centre as

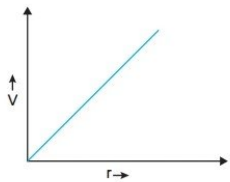
(*a*)



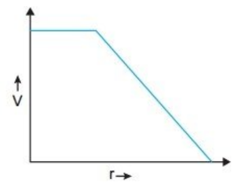
(*b*)



(*c*)



(*d*)



15. A conducting sphere of radius R is given a charge Q. The electric potential and the electric field at the centre of the sphere respectively are

(*a*) zero and $\dfrac{Q}{4\pi\varepsilon_0 R^2}$

(*b*) $\dfrac{Q}{4\pi\varepsilon_0 R}$ and zero

(*c*) $\dfrac{Q}{4\pi\varepsilon_0 R}$ and $\dfrac{Q}{4\pi\varepsilon_0 R^2}$

(*d*) both are zero

16. Four point charges $-Q$, $-q$, $2q$ and $2Q$ are placed, one at each corner of the square. The relation between Q and q for which the potential at the centre of the square is zero is

(*a*) $Q = \dfrac{1}{2}q$

(*b*) $Q = -q$

(*c*) $Q = -\dfrac{1}{2}q$

(*d*) $Q = q$

17. An electric dipole consisting of charges $+q$ and $-q$ separated by a distance L is in stable equilibrium in a uniform electric field $\vec{E}$. The electrostatic potential energy of the dipole is
[*CBSE 2020 (55/1/1)*]

(*a*) qLE

(*b*) zero

(*c*) $-qLE$

(*d*) $-2\,qEL$

18. If a positive charge in displaced against the electric field in which it was situated, then
[*CBSE 2020 (55/3/1)*]

(*a*) work will be done by the electric field on the charge.

(*b*) the intensity of the electric field decreases.

(*c*) energy of the system will decrease.

(*d*) energy will be provided by external source displacing the charge.

19. The capacitors of capacitances C_1 and C_2 are connected in parallel. If a charge Q is given to the combination, the ratio of the charge on the capacitor C_1 to the charge on C_2 will be
[*CBSE 2020 (55/3/1)*]

(*a*) $\dfrac{C_1}{C_2}$

(*b*) $\sqrt{\dfrac{C_1}{C_2}}$

(*c*) $\sqrt{\dfrac{C_2}{C_1}}$

(*d*) $\dfrac{C_2}{C_1}$

20. A charge Q is kept at the centre of a circle of radius r. A test charge q_0, is carried from a point X to the point Y on this circle such that arc XY subtends an angle of 60° at the centre of the circle. The amount of work done in this process will be [*CBSE 2020 (55/3/2)*]

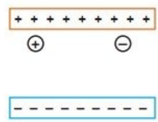
(*a*) $\frac{1}{4\pi\varepsilon_0}\frac{Qq_0}{2r}$ (*b*) $\frac{1}{4\pi\varepsilon_0}\frac{\sqrt{3}Qq_0}{2r}$

(*c*) zero (*d*) $\frac{1}{4\pi\varepsilon_0}\frac{\sqrt{3}Qq_0}{r}$

21. A charge Q is uniformly distributed over the surface of a spherical shell of radius R. The work done in bringing a test charge Q_0 from its centre to its surface is [*CBSE 2020 (55/3/3)*]

(*a*) $\frac{1}{4\pi\varepsilon_0}\frac{QQ_0}{R}$ (*b*) $\frac{1}{4\pi\varepsilon_0}\frac{QQ_0}{2R}$ (*c*) $\frac{QQ_0}{\varepsilon_0 R}$ (*d*) zero

22. A free electron and a free proton are placed between two oppositely charged parallel plates. Both are closer to the positive plate than the negative plate. [*CBSE Sample Paper-2022, Term-1*]



Which of the following statements is true?

I. The force on the proton is greater than the force on the electron.

II. The potential energy of the proton is greater than that of the electron.

III. The potential energy of the proton and the electron is the same.

(*a*) I only (*b*) II only (*c*) III and I only (*d*) II and I only

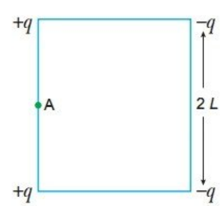
23. Two charges 14 μC and – 4 μC are placed at (–12 cm, 0, 0) and (12 cm, 0, 0) in an external electric field $E = \left(\frac{B}{r^2}\right)$, (where $B = 1.2 \times 10^6$ N/Cm^2) and r is in metres. The electrostatic potential energy of the configuration is [*CBSE 2022 (55/2/4), Term-1*]

(*a*) 97.9 J (*b*) 102.1 J (*c*) 2.1 J (*d*) – 97.9 J

24. A variable capacitor is connected to a 200 V battery. If its capacitance is changed from 2 μF to X μF, the decrease in energy of the capacitor is 2×10^{-2} J. The value of X is [*CBSE 2022 (55/2/4), Term-1*]

(*a*) 1 (*b*) 2 (*c*) 3 (*d*) 4

25. Four charges $-q$, $-q$ and $+q$ are placed at the corners of a square of side 2 L is shown in figure. The electric potential at point A midway between the two charges + q and +q is [*CBSE 2022 (55/2/4), Term-1*]



(*a*) $\frac{1}{4\pi\varepsilon_0}\frac{2q}{L}\left(1-\frac{1}{\sqrt{5}}\right)$ (*b*) $\frac{1}{4\pi\varepsilon_0}\frac{2q}{L}\left(1+\frac{1}{\sqrt{5}}\right)$

(*c*) $\frac{1}{4\pi\varepsilon_0}\frac{q}{2L}\left(1-\frac{1}{\sqrt{5}}\right)$ (*d*) zero

26. Three charges $2q$, $-q$ and $-q$ lie at the vertices of a triangle. The value of E and V at centroid of triangle will be [*CBSE Sample Paper-2022, Term-1*]

(*a*) $E \neq 0$ and $V \neq 0$ (*b*) $E = 0$ and $V = 0$

(*c*) $E \neq 0$ and $V = 0$ (*d*) $E = 0$ and $V \neq 0$

27. **Two parallel plate capacitors X and Y, have the same area of plates and same separation between plates. X has air and Y with dielectric of constant 2 , between its plates. They are connected in series to a battery of 12 V. The ratio of electrostatic energy stored in X and Y is**

[*CBSE Sample Paper-2022, Term-1*]

(*a*) 4:1 (*b*) 1:4 (*c*) 2:1 (*d*) 1:2

28. **A capacitor plates are charged by a battery with 'V' volts. After charging, battery is disconnected and a dielectric slab with dielectric constant 'K' is inserted between its plates, the potential across the plates of a capacitor will become** [*CBSE Sample Paper-2022, Term-1*]

(*a*) zero (*b*) $V/2$ (*c*) V/K (*d*) KV

29. **Three capacitors 2μF, 3μF and 6μF are joined in series with each other. The equivalent capacitance is** [*CBSE Sample Paper-2022, Term-1*]

(*a*) 1/2 μF (*b*) 1 μF (*c*) 2 μF (*d*) 11 μF

30. **Which of the following is NOT the property of equipotential surface?**

[*CBSE Sample Paper-2022, Term-1)*]

(*a*) They do not cross each other.
(*b*) The rate of change of potential with distance on them is zero.
(*c*) For a uniform electric field they are concentric spheres.
(*d*) They can be imaginary spheres.

31. **A point P lies at a distance x from the mid point of an electric dipole on its axis. The electric potential at point P is proportional to** [*CBSE 2023 (55/2/1)*]

(*a*) $\frac{1}{x^2}$ (*b*) $\frac{1}{x^3}$ (*c*) $\frac{1}{x^4}$ (*d*) $\frac{1}{x^{1/2}}$

Answers

1. (*c*)	**2.** (*c*)	**3.** (*c*)	**4.** (*c*)	**5.** (*a*)	**6.** (*b*)	**7.** (*b*)
8. (*c*)	**9.** (*a*), (*b*), (*c*)	**10.** (*c*)	**11.** (*b*)	**12.** (*a*)	**13.** (*a*)	**14.** (*b*)
15. (*b*)	**16.** (*b*)	**17.** (*c*)	**18.** (*d*)	**19.** (*a*)	**20.** (*c*)	**21.** (*d*)
22. (*b*)	**23.** (*a*)	**24.** (*a*)	**25.** (*a*)	**26.** (*c*)	**27.** (*c*)	**28.** (*c*)
29. (*b*)	**30.** (*c*)	**31.** (*a*)				

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(a) ***Both A and R are true and R is the correct explanation of A.***
(b) ***Both A and R are true but R is not the correct explanation of A.***
(c) ***A is true but R is false.***
(d) ***A is false and R is also false.***

1. **Assertion(A)** : A capacitor can be given only a limited amount of charge.
Reason (R) : After a limited value of charge, the dielectric strength of dielectric between the capacitor plates breaks down.

2. **Assertion(A)** : An applied electric field polarises a polar dielectric.
Reason (R) : The molecules of a polar dielectric possess a permanent dipole moment, but in the absence of electric field, these dipoles are randomly oriented and when electric field is applied these dipoles align along the direction of electric field.

3. **Assertion (A)** : Electric field is always normal to equipotential surfaces and along the direction of decreasing order of potential.
Reason (R) : Negative gradient of electric potential is electric field. [*CBSE Sample Paper 2021*]

4. **Assertion (A)** : The capacitance of a parallel plate capacitor increases with increase of distance between the plates.
Reason (R) : Capacitance of a parallel plate capacitor *i.e.*, $C \propto d$

5. **Assertion (A)** : The capacitance of a conductor does not depend on the charge given to it.
Reason (R) : The capacitance of a conductor depends only on geometry and size of conductor.

6. **Assertion (A)** : When a charged capacitor is filled completely with a metallic slab, its capacitance is increased by a large amount.
Reason (R) : The dielectric constant for metal is infinite.

7. **Assertion (A)** : The surface of a conductor is always an equipotential surface.
Reason (R) : A conductor contains free electrons which can move freely to equalise the potential.

8. **Assertion (A)** : When charged capacitors are connected in parallel, the algebraic sum of charges remains constant but there is a loss of energy.
Reason (R) : During sharing a charges, the energy conservation law does not hold.

9. **Assertion (A)** : In the absence of an externally applied electric field, the displacement per unit volume of a polar dielectric material is always zero.
Reason (R) : In polar dielectrics, each molecule has a permanent dipole moment but these are randomly oriented in the absence of an externally applied electric field.
[*AIIMS 2018*]

10. **Assertion (A)** : Work done in moving a charge around a closed path, in an electric field is always zero. [*CBSE 2023 (55/2/1)*]
Reason (R) : Electrostatic force is a conservative force.

Answers

1. (*a*)	**2.** (*a*)	**3.** (*b*)	**4.** (*d*)	**5.** (*a*)	**6.** (*a*)	**7.** (*a*)
8. (*c*)	**9.** (*a*)	**10.** (*a*)				

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Case-based/Passage-based Questions

Read the paragraph given below and answer the questions that follow:

1. **Faraday Cage:** A Faraday cage or Faraday shield is an enclosure made of a conducting material. The fields within a conductor cancel out with any external fields, so the electric field within the enclosure is zero. These Faraday cages act as big hollow conductors you can put things in to shield them from electrical fields. Any electrical shocks the cage receives, pass harmlessly around the outside of the cage.

[*CBSE Sample Paper 2021*]

(*i*) **Which of the following material can be used to make a Faraday cage?**
(*a*) Plastic (*b*) Glass (*c*) Copper (*d*) Wood

(*ii*) **Example of a real-world Faraday cage is**
(*a*) car (*b*) plastic box (*c*) lightning rod (*d*) metal rod

(iii) What is the electrical force inside a Faraday cage when it is struck by lightning?

(*a*) The same as the lightning

(*b*) Half that of the lightning

(*c*) Zero

(*d*) A quarter of the lightning

(iv) An isolated point charge $+q$ is placed inside the Faraday cage. Its surface must have charge equal to

(*a*) zero (*b*) $+q$

(*c*) $-q$ (*d*) $+2q$

OR

A point charge of 2 μC is placed at centre of Faraday cage in the shape of cube with surface of 9 cm edge. The number of electric field lines passing through the cube normally will be

(*a*) 1.9×10^5 Nm^2/C entering the surface

(*b*) 1.9×10^5 Nm^2/C leaving the surface

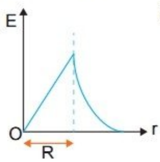
(*c*) 2.0×10^5 Nm^2/C leaving the surface

(*d*) 2.0×10^5 Nm^2/C entering the surface

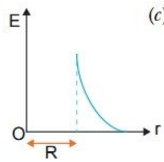
2. **Electrostatics:** Electrostatics deals with the study of forces, fields and potentials arising from static charges. Force and eletric field, due to a point charge is basically determined by Coulomb's law. For symmetric charge configurations, Gauss's law, which is also based on Coulomb's law, helps us to find the electric field. A charge a system of charges like a dipole experience a force/torque in an electric field. Work is required to be done to provide a specific orientation to a dipole with respect to an electric field. *[CBSE 2023 (55/4/1), Modified]*

(i) Consider a uniformly charged thin conducting shell of radius R. Which of the following graph showing the variation of $|\vec{E}|$ with distance r from the centre, for points $0 \le r \le 3r$.

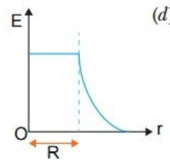
(*a*)



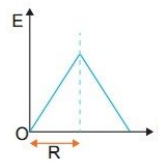
(*b*)



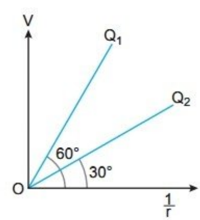
(*c*)



(*d*)



(ii) The figure shows the variation of potential V with $\frac{1}{r}$ for two point charges Q_1 and Q_2, where V is the potential at a distance r due to a point charge. The ratio, $\frac{Q_1}{Q_2}$ will be



(*a*) 1:3 (*b*) 3:1

(*c*) 2:1 (*d*) 1:2

(iii) An electric dipole of dipole moment of 6×10^{-7} C-m is kept in a uniform electric field of 10^4 N/C such that the dipole moment and the electric field are parallel. The potential energy of the dipole will be

(*a*) 2×10^3J (*b*) -2×10^3J (*c*) -6×10^{-3}J (*d*) 6×10^{-3}J

(iv) A dipole is placed parallel to electric field. If W is the work done in rotating the dipole from 0° to 60°, then work done in rotating it from 0° to 180° is

(*a*) 2 W (*b*) 3 W (*c*) 4 W (*d*) $\frac{W}{2}$

OR

The electric potential V at any point x, y, z (all in metres) in space is given by $V = 4x^2$ volt. The electric field at the point (1 m, 0, 2 m) in volt/metre is

(*a*) 8 along negative x-axis (*b*) 8 along positive x-axis

(*c*) 16 along negative x-axis (*d*) 16 along positive z-axis

Explanations

1. (*i*) (*c*) Copper (Electric field inside a conductor is zero.)

(*ii*) (*a*) car (Body of the car is made up of conductor.)

(*iii*) (*c*) Zero (As electric field inside it is zero.)

(*iv*) (*c*) $-q$ (As from Gauss's law q_{in} must be zero for electric field inside it is zero.)

OR

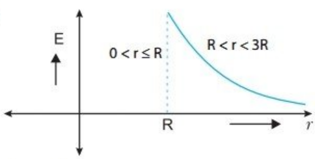
(*c*) $q = 2\ \mu C = 2 \times 10^{-6}$ C

$$\varepsilon_0 = 8.85 \times 10^{-12} \frac{Nm^2}{C^2}$$

Now, total number of electric field lines $= \frac{q_{in}}{\varepsilon_0} = \frac{2 \times 10^{-6}}{8.85 \times 10^{-12}}$

$$= 2.2 \times 10^5 \frac{Nm^2}{C} \text{ leaving the surface}$$

2. (*i*) (*b*)



(*ii*) (*b*) As we know,

$$V = \frac{KQ}{r} \quad \Rightarrow \quad Q = \frac{V}{k\left(\frac{1}{r}\right)} \qquad [k = \text{contant} = 9 \times 10^9\ Nm^2/C^2]$$

So, slope of V verses $\frac{1}{r}$ curve gives value of charge.

From the graph,

$$\text{Ratio, } \frac{Q_1}{Q_2} = \frac{\tan\theta_1}{\tan\theta_2} = \frac{\tan 60°}{\tan 30°} = \frac{\sqrt{3}}{\frac{1}{\sqrt{3}}} = 3.$$

(*iii*) (*c*) Here, $p = 6 \times 10^{-7}$ Cm, $E = 10^4$ N/C, $\theta = 0°$

Potential energy, $U = pE\cos\theta = -6 \times 10^{-7} \times 10^4 \times \cos 0° = -6 \times 10^{-3}$J

(*iv*) (*c*) $W = PE(\cos\theta_1 - \cos\theta_2)$

$$= PE(\cos 0° - \cos 60°)$$

$$= PE\left(1 - \frac{1}{2}\right) = \frac{1}{2}PE$$

And $W' = PE(\cos 0° - \cos 180°) = PE\{1 - (-1)\} = 2PE$

$$\text{Now, } \frac{W}{W'} = \frac{\frac{1}{2}PE}{2PE} = \frac{1}{4}$$

$$\therefore \quad W' = 4W$$

OR

(a) $E_x = -\frac{dV}{dx} = -\frac{d}{dx}(4x^2)$

$= -8x = -8 \times 1 = -8$ V/m

$\therefore \vec{E} = -8\,\hat{x}$ or 8 V/m along negative x-axis

CONCEPTUAL QUESTIONS

Q. 1. A charged particle $(+q)$ moves in a uniform electric field $(\vec{E})$ in the direction opposite to $\vec{E}$. What will be the effect on its electrostatic potential energy during its motion?

[CBSE 2020 (55/4/3)]

Ans. As we know, $\Delta U = -W = -q\int E.dl$

When charge $+q$ moves in opposite direction to electric field then work done is negative.

$\Delta U = -W$

so, change in potential energy is positive, the potential energy increases.

Q. 2. Why is the electrostatic potential inside a charged conducting shell constant throughout the volume of the conductor? *[CBSE 2019 (55/5/1)]*

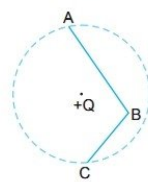
Ans. $E = 0$ inside the conductor & has no tangential component on the surface.

$\therefore$ No work is done in moving charge inside or on the surface of the conductor. & Potential is constant. **1**

[Even if a student writes "because $E = 0$ inside the conductor" - award full marks Or No work is done in moving a charge inside the conductor - award full marks.]

[CBSE Marking Scheme 2019 (55/5/1)]

Q. 3. In the given figure, charge $+Q$ is placed at the centre of a dotted circle. Work done in taking another charge $+q$ from A to B is W_1 and from B to C is W_2. Which one of the following is correct: $W_1 > W_2$, $W_1 = W_2$ and $W_1 < W_2$? *[CBSE Sample Paper 2018]*



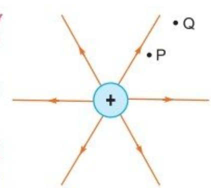
Ans. The points A and C are at same distance from the charge $+Q$ at the centre, so

$V_A = V_C$

Therefore, $V_A - V_B = V_C - V_B$

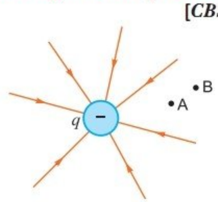
Hence, the magnitude of work done in taking charge $+q$ from A to B or from B to C will be the same *i.e.*, $W_1 = W_2$.

Q. 4. Figure shows the field lines on a positive charge. Is the work done by the field in moving a small positive charge from Q to P positive or negative? Give reason. *[CBSE (F) 2014]*



Ans. The work done by the field is negative. This is because the charge is moved against the force exerted by the field.

Q. 5. The field lines of a negative point charge are as shown in the figure. Does the kinetic energy of a small negative charge increase or decrease in going from B to A? *[CBSE Patna 2015]*



Ans. The kinetic energy of a negative charge decreases while going from point B to point A, against the movement of force of repulsion.

Q. 6. A point charge $+Q$ is placed at point O as shown in the figure. Is the potential difference $V_A – V_B$ positive, negative or zero? **[*CBSE Delhi 2016*]**

Ans. The potential due to a point charge decreases with increase of distance. So, $V_A - V_B$ is positive.

Explanation: Let the distance of point A and B from charge Q be r_A and r_B respectively.

$$V_A = \frac{+Q}{4\pi\varepsilon_0 r_A} \text{ and } V_B = \frac{+Q}{4\pi\varepsilon_0 r_B}$$

$$V_A - V_B = \frac{+Q}{4\pi\varepsilon_0}\left(\frac{1}{r_A} - \frac{1}{r_B}\right)$$

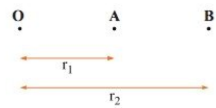
Also $r_A < r_B$

$$\Rightarrow \frac{1}{r_A} > \frac{1}{r_B} \quad \Rightarrow \frac{1}{r_A} - \frac{1}{r_B} > 0 \quad \Rightarrow \quad \frac{1}{r_A} - \frac{1}{r_B} \text{ has positive value}$$

Also Q is positive.

Hence $V_A - V_B$ is positive.

Q. 7. A point charge Q is placed at point 'O' as shown in figure. Is the potential at point A, *i.e.*, V_A, greater, smaller or equal to potential, V_B, at point B, when Q is (*i*) positive, and (*ii*) negative charge? **[*CBSE (F) 2017*]**



Ans. (*i*) If Q is positive,

$$V_A = \frac{KQ}{r_1} \quad \text{and} \quad V_B = \frac{KQ}{r_2}$$

Clearly, $V_A > V_B$

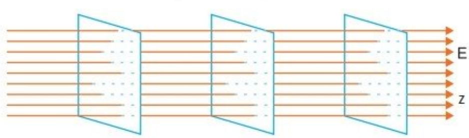
(*ii*) If Q is negative,

$$V_A = -\frac{KQ}{r_1} \quad \text{and} \quad V_B = -\frac{KQ}{r_2}$$

Clearly, $V_A < V_B$

Q. 8. Draw the equipotential surfaces corresponding to a uniform electric field in the *z*-direction. **[*CBSE 2019 (55/1/1)*]**

Ans. The equipotential surfaces are the equidistant planes normal to the *z*-axis, *i.e.*, planes parallel to the *X–Y* plane.



Q. 9. A point charge Q is placed at point O as shown in the figure. The potential difference $V_A - V_B$ is positive. Is the charge Q negative or positive? **[*CBSE (F) 2016*]**

Ans. We know that, $V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$

$$\Rightarrow \qquad V \propto \frac{1}{r}$$

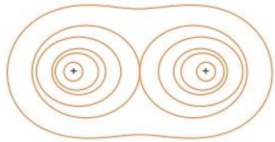
The potential due to a point charge decreases with increase of distance.

$$V_A - V_B > 0 \qquad \Rightarrow \qquad V_A > V_B$$

Hence, the charge Q is positive.

Q. 10. Depict the equipotential surfaces for a system of two identical positive point charges placed a distance '*d*' apart. [*CBSE Delhi 2010*]

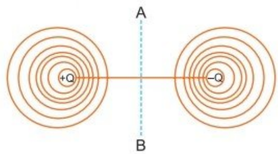
Ans. Equipotential surfaces due to two identical charges is shown in figure.



Q. 11. Draw an equipotential surface for a system consisting of two charges Q, – Q separated by a distance *r* in air. Locate the points where the potential due to the dipole is zero.

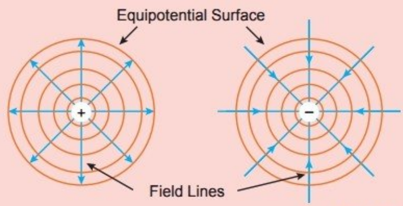
[*CBSE Delhi 2017, (AI) 2008, 2013, 2019 (55/2/1), 2020 (55/4/2)*]

Ans. The equipotential surface for the system is as shown. Electric potential is zero at all points in the plane passing through the dipole equator *AB*.



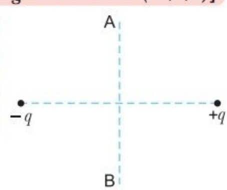
Q. 12. Draw the equipotential surfaces due to an isolated point charge. [*CBSE 2019 (55/1/2)*]

Ans. 1



[*CBSE Marking Scheme 2019 (55/1/2)*]

Q. 13. A charge '*q*' is moved from a point *A* above a dipole of dipole moment '*p*' to a point *B* below the dipole in equatorial plane without acceleration. Find the work done in the process. [*CBSE Central 2016*]



Ans. Work done in the process is zero. Because, equatorial plane of a dipole is equipotential surface and work done in moving charge on equipotential surface is zero.

$$W = qV_{AB} = q \times 0 = 0$$

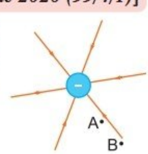
Q. 14. The work done in moving a charge particle between two points in an uniform electric field does not depend on the path followed by the particle. Why? [*CBSE 2020 (55/4/1)*]

Ans. Because the electrostatic force is conservative in nature 1

Alternatively:-

Electric field is conservative in nature / work done by or against the electric field does not depend upon the path followed. [*CBSE Marking Scheme 2020 (55/4/1)*]

Q. 15. Figure shows the field lines due to a negative point charge. Give the sign of the potential energy difference of a small negative charge between the points *A* and *B*. [*CBSE (F) 2014*]



Ans. $$U = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r}$$

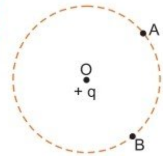
Since $\quad r_A < r_B$

$$\therefore \quad \frac{kq_1q_2}{r_A} > \frac{kq_1q_2}{r_B}$$

$$\therefore \quad U_A > U_B$$

Therefore, $U_A - U_B$ is positive.

Q. 16. What is the amount of work done in moving a point charge Q around a circular arc of radius 'r' at the centre of which another point charge 'q' is located? *[CBSE North 2016]*



Ans. The potential of points A and B are same being equal to

$$V_A = V_B = \frac{1}{4\pi\varepsilon_0}\frac{q}{R}$$

where R is the radius of the circle.

Work done $W = q\,(V_B - V_A) = q\,(V_A - V_A) = 0$.

Q. 17. A 12 pF capacitor is connected to a 50 V battery. How much electrostatic energy is stored in the capacitor? *[NCERT]*

Ans. Electrostatic energy stored in capacitor, $U = \frac{1}{2}CV^2$

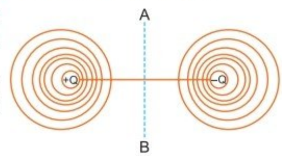
Here $C = 12 \text{ pF} = 12 \times 10^{-12}$ F, $V = 50$ V

$$\therefore \quad U = \frac{1}{2} \times 12 \times 10^{-12} \times (50)^2 = \mathbf{1.5 \times 10^{-8}\ J}$$

Q. 18. Do free electrons travel to region of higher potential or lower potential? *[NCERT Exemplar]*

Ans. Free electrons would travel to regions of higher potentials as they are negatively charged.

Q. 19. Show that the equipotential surfaces are closed together in the regions of strong field and far apart in the regions of weak field. Draw equipotential surfaces for an electric dipole. *[CBSE Sample Paper 2016]*



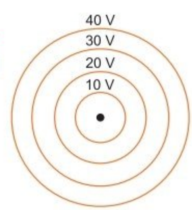
Ans. Equipotential surfaces are closer together in the regions of strong field and farther apart in the regions of weak field.

$$E = -\frac{dV}{dr}$$

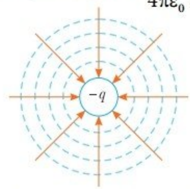
E = negative potential gradient

For same change in dV, $E \propto \frac{1}{dr}$ where 'dr' represents the distance between equipotential surfaces.

Q. 20. Concentric equipotential surfaces due to a charged body placed at the centre are shown. Identify the polarity of the charge and draw the electric field lines due to it. *[HOTS][CBSE Sample Paper 2016]*



Ans. For a single charge the potential is given by $V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$



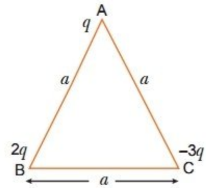
This shows that V is constant if r is constant. Greater the radius smaller will be the potential. In the given figure, potential is decreasing towards the centre of concentric equipotential surface. This shows that the polarity of charge is negative ($-\,q$). The direction of electric field will be radially inward. The field lines are directed from higher to lower potential.

Very Short Answer Questions

Each of the following questions are of 2 marks.

Q. 1. Obtain an expression for electrostatic potential energy of a system of three charges q, $2q$ and $-3q$ placed at the vertices of an equilateral triangle of side a. **[*CBSE 2023 (55/4/1)*]**

Ans. For the system of three charges at vertices of equilateral triangle,



$P.E$ of each pair of charges, $U = \dfrac{k\,q_1 q_2}{r}$

then, $U_{AB} = \dfrac{k(q)(2q)}{a} = \dfrac{2kq^2}{a}$

And $U_{BC} = \dfrac{k(2q)(-3q)}{a} = \dfrac{-6kq^2}{a}$

$U_{CA} = \dfrac{k(q)(-3q)}{r} = \dfrac{-3kq^2}{a}$

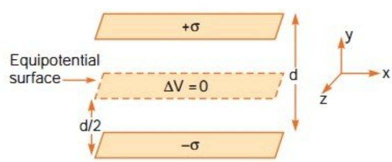
$\therefore$ Total Energy, $U = U_{AB} + U_{BC} + U_{CA}$

$$= \frac{kq^2}{a}[2-6-3] = -\frac{7kq^2}{a} \qquad \left[k = \frac{1}{4\pi\varepsilon_0}\right]$$

$$= -\frac{1}{4\pi\varepsilon_0}\left(\frac{7q^2}{a}\right)$$

Q. 2. Two uniformly large parallel thin plates having charge densities $+\sigma$ and $-\sigma$ are kept in the X-Z plane at a distance 'd' apart. Sketch an equipotential surface due to electric field between the plates. If a particle of mass m and charge '$-q$' remains stationary between the plates, what is the magnitude and direction of this field? **[*CBSE Delhi 2011*]**

Ans. The equipotential surface is at a distance $d/2$ from either plate in X-Z plane. For a particle of charge $(-q)$ at rest between the plates, then



(*i*) weight mg acts vertically downward

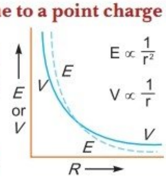
(*ii*) electric force qE acts vertically upward.

So, $mg = qE$

$E = \dfrac{mg}{q}$, vertically downward, *i.e.*, along $-Y$-axis.

Q. 3. Plot a graph comparing the variation of potential 'V' and electric field 'E' due to a point charge 'Q' as a function of distance 'R' from the point charge. **[*CBSE Delhi 2012*]**

Ans. The graph of variation of potential and electric field due to a point charge Q with distance R from the point charge is shown in figure.



Q. 4. What is electrostatic shielding? How is this property used in actual practice? Is the potential in the cavity of a charged conductor zero? **[*CBSE South 2016*]**

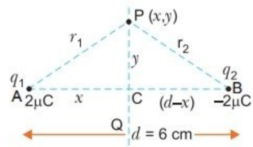
Ans. Whatever be the charge and field configuration outside, any cavity in a conductor remains shielded from outside electric influence. The field inside a conductor is zero. This is known as electrostatic shielding.

- Sensitive instruments are shielded from outside electrical influences by enclosing them in a hollow conductor.
- During lightning it is safest to sit inside a car, rather than near a tree. The metallic body of a car becomes an electrostatic shielding from lightening.

Potential inside the cavity is not zero. Potential is constant.

Q. 5. Two charges 2 μC and – 2 μC are placed at points *A* and *B* 6 cm apart.
(*a*) Identify an equipotential surface of the system.
(*b*) What is the direction of the electric field at every point on this surface? **[*NCERT*]**

Ans. (*a*) Let $P(x, y)$ be a point on zero potential surface. Let A (location of charge $q = 2\ \mu C$) be origin of coordinate system.



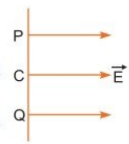
Distance $r_1 = \sqrt{x^2 + y^2}$, Distance $r_2 = \sqrt{(d - x)^2 + y^2}$

where $d = 6\text{ cm} = 6 \times 10^{-2}\text{ m}$.

Potential at P due to charges $q_1 = +2\ \mu C$ and $q_2 = -2\ \mu C$ is given by

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r_1} + \frac{1}{4\pi\varepsilon_0}\frac{q_2}{r_2} = 0 \Rightarrow \frac{1}{4\pi\varepsilon_0}\frac{2\times10^{-6}}{\sqrt{x^2+y^2}} + \frac{1}{4\pi\varepsilon_0}\frac{(-2\times10^{-6})}{\sqrt{(d-x)^2+y^2}} = 0$$

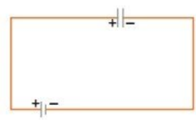
or $$\frac{1}{\sqrt{x^2+y^2}} = \frac{1}{\sqrt{(d-x)^2+y^2}} \Rightarrow x^2 + y^2 = (d-x)^2 + y^2 \Rightarrow x = \frac{d}{2} = \mathbf{3\ cm}$$



So, plane passing through mid point of line joining A and B has zero potential everywhere.

(*b*) The direction of electric field is normal to surface PCQ everywhere as shown in figure.

Q. 6. Why does current in a steady state not flow in a capacitor connected across a battery? However momentary current does flow during charging or discharging of the capacitor. Explain. **[*CBSE (AI) 2017*]**



Ans. (*i*) In the steady state no current flows through capacitor because, we have two sources (battery and fully charged capacitor) of equal potential connected in opposition.

(*ii*) During charging or discharging there is a momentary flow of current as the potentials of the two sources are not equal to each other.

Q. 7. Consider two identical point charges located at points (0, 0) and (*a*, 0).
1. Is there a point on the line joining them at which the electric field is zero?
2. Is there a point on the line joining them at which the electric potential is zero?
Justify your answers for each case. **[*CBSE 2023 (55/2/1)*]**

Ans. 1. Yes, electric field will zero at mid point.

Electric field being a vector quantity, its resultant is zero.

2. No, potential cannot be zero on line joining the charges.

Electric potential being a scalar quantity, the net potential due to two identical charges cannot be zero.

Q. 8. Two small conducting balls *A* and *B* of radius r_1 and r_2 have charges q_1 and q_2 respectively. They are connected by a wire. Obtain the expression for charges on *A* and *B*, in equilibrium.

Ans. According to law of conservation of charge, **[*CBSE 2023 (55/4/1)*]**

$$q_i = q_f$$

$$q_1 + q_2 = q'_1 + q'_2 = Q$$

When two balls are connected with wire,

$$V_1 = V_2$$

$$\Rightarrow \qquad \frac{kq'_1}{r_1} = \frac{kq'_2}{r_2} \text{ or } \frac{q'_1}{r_1} = \frac{q'_2}{r_2}$$

$$\Rightarrow \qquad q'_1 r_2 = q'_2 r_1$$

$$\Rightarrow \qquad q'_1 r_2 = (Q - q'_1) r_1$$

$$\Rightarrow \qquad q'_1 r_2 = Q r_1 - q'_1 r_1$$

$$\Rightarrow \qquad q'_1 (r_1 + r_2) = Q r_1$$

$$\therefore \qquad q'_1 = \frac{Q r_1}{r_1 + r_2} = \frac{(q_1 + q_2) r_1}{r_1 + r_2}$$

And, $$q'_2 = Q - q'_1 = Q - \frac{Q r_1}{r_1 + r_2}$$

$$= \frac{Q r_2}{r_1 + r_2} = \frac{(q_1 + q_2) r_2}{r_1 + r_2}$$

Q. 9. (*a*) A parallel plate capacitor (C_1) having charge Q is connected, to an identical uncharged capacitor C_2 in series. What would be the charge accumulated on the capacitor C_2?

(*b*) Three identical capacitors each of capacitance 3 μF are connected, in turn, in series and in parallel combination to the common source of V volt. Find out the ratio of the energies stored in two configurations. ***[CBSE South 2016]***

Ans. (*a*) Since the capacitor C_2 is uncharged so when connected to an identical capacitor C_1 charged to Q then charge Q is equally shared and charge acquired by capacitor C_2 is $\frac{Q}{2}$.

(*b*) We have $C_{series} = \frac{3\mu F}{3} = 1\mu F$

Also, $C_{parallel} = (3 + 3 + 3) = 9\ \mu F$

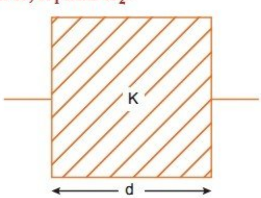
Energy stored $= \frac{1}{2} C V^2$

$\therefore$ Energy in series combination $= \frac{1}{2} \times 1 \times 10^{-6} \times V^2 \quad \Rightarrow \quad U_{Series} = \frac{10^{-6}}{2} V^2$

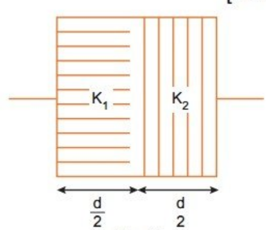
$\therefore$ Energy in parallel combination $= \frac{1}{2} \times 9 \times 10^{-6} \times V^2 \quad \Rightarrow \quad U_{parallel} = \frac{10^{-6} \times 9}{2} V^2$

$\therefore$ $U_{series} : U_{parallel} = \mathbf{1 : 9}$

Q. 10. The space between the plates of a parallel plate capacitor is completely filled in two ways. In the first case, it is filled with a slab of dielectric constant K. In the second case, it is filled with two slabs of equal thickness and dielectric constants K_1 and K_2 respectively as shown in the figure. The capacitance of the capacitor is same in the two cases. Obtain the relationship between K, K_1 and K_2. ***[CBSE 2020 (55/1/1)]***



(Case 1)



(Case 2)

Ans. **Case I:** $C_1 = \frac{K \varepsilon_0 A}{d}$

Case II: It is filled with two slabs of equal thickness with dielectric constants K_1 and K_2 respectvely in given such way. So it behave as a capacitors are connected in series.

C_2 = Series combination of two capacitors (let)

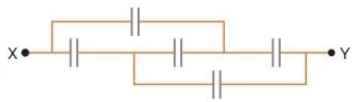
$$C' = \frac{K_1 \varepsilon_0 A}{d/2}, \; C'' = \frac{K_2 \varepsilon_0 A}{d/2}$$

$$\Rightarrow \quad \frac{1}{C_2} = \frac{1}{C'} + \frac{1}{C''} = \frac{d}{2K_1 \varepsilon_0 A} + \frac{d}{2K_2 \varepsilon_0 A} = \frac{d}{2\varepsilon_0 A}\left(\frac{K_1 + K_2}{K_1 K_2}\right)$$

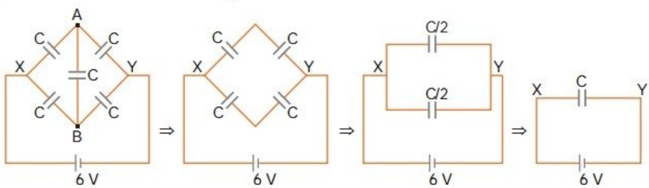
$$\therefore \quad C_2 = \frac{2\varepsilon_0 A}{d}\left(\frac{K_1 K_2}{K_1 + K_2}\right)$$

$$\because \quad C_1 = C_2 \text{ (given)} \quad \Rightarrow \quad \frac{K\varepsilon_0 A}{d} = \frac{2\varepsilon_0 A}{d}\left(\frac{K_1 K_2}{K_1 + K_2}\right) \quad \Rightarrow \quad \boldsymbol{K = \frac{2K_1 K_2}{K_1 + K_2}}$$

Q. 11. Find the equivalent capacitance of the network shown in the figure, when each capacitor is of 1 μF. When the ends *X* and *Y* are connected to a 6 V battery, find out (*i*) the charge and (*ii*) the energy stored in the network. **[*CBSE Patna 2015*]**



Ans. The given circuit can be rearranged as



It is known as wheatstone bridge of the capacitor.

Since $V_A = V_B$, so the bridge capacitor between points *A* and *B* can be removed.

(*i*) The equivalent capacitor of the network

$$C_{eq} = \frac{C \times C}{C + C} + \frac{C \times C}{C + C}$$

$$= \frac{C}{2} + \frac{C}{2} = C = 1\mu\text{F}$$

Charge in the network, $Q = C_{eq} V = C \times V$

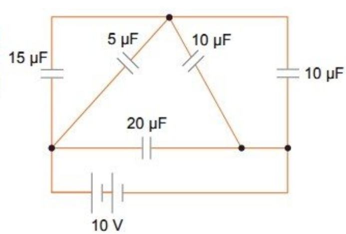
$$= 1\,\mu\text{F} \times 6\text{ V} = \mathbf{6\,\mu C}$$

(*ii*) Energy stored in the capacitor,

$$U = \frac{1}{2} C_{eq} V^2 = \frac{1}{2} \times 1\,\mu\text{F} \times (6)^2$$

$$= \mathbf{18\,\mu J}$$

Q. 12. The figure shows a network of five capacitors connected to a 10 V battery. Calculate the charge acquired by the 5 μF capacitor. **[*CBSE 2019 (55/3/3)*]**



Ans. Net capacitance of parallel C_1 & $C_2 = C_1 + C_2$

$C_{12} = 15 + 5 = 20\,\mu$F

Net capacitance of parallel C_4 & $C_5 = C_4 + C_5$

$C_{45} = 10 + 10 = 20\,\mu$F

C_{12}, C_{45} in series, $C_{1245} = \dfrac{C_{12}C_{45}}{C_{12}+C_{45}} = \dfrac{20\times 20}{20+20} = 10\,\mu\text{F}$

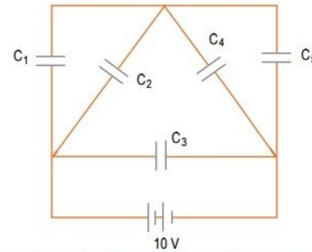
C_3 in parallel with $C_{1245} = C_{1245} + C_3 = 10 + 20 = 30\,\mu\text{F}$

P.D. across $C_{1245} = 10$ V

P.D. across $C_{12} = C_{45} = 5$ V

Charge on $5\,\mu\text{F}$, $Q = CV$

$= 5 \times 10^{-6} \times 5\text{ C} = \mathbf{25 \times 10^{-6}\ C}$



Q. 13. Four charges $+q, -q, +q$ and $-q$ are to be arranged respectively at the four corners of a square *ABCD* of side '*a*'.

(*a*) Find the work required to put together this arrangement.

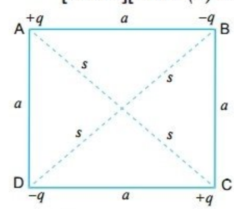
(*b*) A charge q_0 is brought to the centre of the square, the four charges being held fixed. How much extra work is needed to do this? **[*HOTS*][*CBSE (F) 2015*]**

Ans. (*a*) Work done in bringing charge $+q$ at point A

$W_A = 0$

Work done in bringing charge $-q$ to the point B

$$W_B = W_{AB} = -q \times \frac{1}{4\pi\varepsilon_0}\frac{q}{a} = -\frac{1}{4\pi\varepsilon_0}\frac{q^2}{a}$$



Work done in bring the charge $+q$ to the point C

$$W_C = W_{AC} + W_{BC}$$

$$= q \times \frac{1}{4\pi\varepsilon_0}\frac{q}{a\sqrt{2}} + q \times \left(-\frac{1}{4\pi\varepsilon_0}\frac{q}{a}\right) = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{a\sqrt{2}} - \frac{1}{4\pi\varepsilon_0}\frac{q^2}{a}$$

Work done in bringing a charge $-q$ to the point D

$$W_D = W_{AD} + W_{BD} + W_{CD}$$

$$= -q \times \frac{1}{4\pi\varepsilon_0}\frac{q}{a} + (-q)\left(\frac{1}{4\pi\varepsilon_0}\frac{-q}{a\sqrt{2}}\right) + (-q) \times \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{a}$$

Total work done $W = W_A + W_B + W_C + W_D$

$$= 2 \times \frac{1}{4\pi\varepsilon_0}\frac{q^2}{a\sqrt{2}} - 4 \times \frac{1}{4\pi\varepsilon_0}\frac{q^2}{a} = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{a}(\sqrt{2}-4)$$

(*b*) Work done in bringing a charge from infinity to a point is given by

$W = q_0 V_p$ (V_p = Electric potential at the point)

Electric potential at the centre of the square is, where $s = \dfrac{a}{\sqrt{2}}$

$$V_C = \frac{1}{4\pi\varepsilon_0}\left(\frac{+q}{s}\right) + \frac{1}{4\pi\varepsilon_0}\left(\frac{-q}{s}\right) + \frac{1}{4\pi\varepsilon_0}\left(\frac{+q}{s}\right) + \frac{1}{4\pi\varepsilon_0}\left(\frac{-q}{s}\right) = 0$$

and electric potential at infinity is always zero.

Hence, work done $W = 0$.

Q. 14. Consider two conducting spheres of radii R_1 and R_2 with $R_1 > R_2$. If the two are at the same potential, the larger sphere has more charge than the smaller sphere. State whether the charge density of the smaller sphere is more or less than that of the larger one. **[*HOTS*][*NCERT Exemplar*]**

Ans. Since two spheres are at the same potential, therefore

$V_1 = V_2$

$$\frac{Q_1}{4\pi\varepsilon_0 R_1} = \frac{Q_2}{4\pi\varepsilon_0 R_2}$$

$$\Rightarrow \quad \frac{Q_1}{Q_2} = \frac{R_1}{R_2} \qquad \ldots(i)$$

Given, $\quad R_1 > R_2, \quad \therefore \quad Q_1 > Q_2$

$\Rightarrow$ Larger sphere has more charge

Now, $\quad \sigma_1 = \frac{Q_1}{4\pi R_1^2}$ and $\sigma_2 = \frac{Q_2}{4\pi R_2^2}$

$$\Rightarrow \quad \frac{\sigma_2}{\sigma_1} = \frac{Q_2}{Q_1} \cdot \frac{R_1^2}{R_2^2}$$

$$\Rightarrow \quad \frac{\sigma_2}{\sigma_1} = \frac{R_2}{R_1} \cdot \frac{R_1^2}{R_2^2} = \frac{R_1}{R_2} \qquad \text{[From equation } (i)]$$

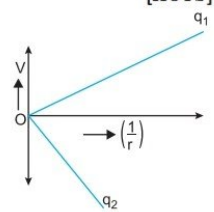
Since $R_1 > R_2$, therefore $\sigma_2 > \sigma_1$.

Charge density of smaller sphere is more than that of larger one.

Q. 15. The two graphs are drawn below, show the variations of electrostatic potential (V) with $\frac{1}{r}$ (r being the distance of field point from the point charge) for two point charges q_1 and q_2.

(*i*) What are the signs of the two charges?

(*ii*) Which of the two charges has the larger magnitude and why? **[*HOTS*]**



Ans. (*i*) The potential due to positive charge is positive and due to negative charge, it is negative, so, q_1 is **positive** and q_2 is **negative**.

(*ii*) $V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$

The graph between V and $\frac{1}{r}$ is a straight line passing through the origin with slope $\frac{q}{4\pi\varepsilon_0}$.

As the magnitude of slope of the line due to charge q_2 is greater than that due to q_1, q_2 has larger magnitude.

Q. 16. Two identical capacitors of 12 pF each are connected in series across a 50 V battery. Calculate the electrostatic energy stored in the combination. If these were connected in parallel across the same battery, find out the value of the energy stored in this combination. **[*CBSE 2019 (55/5/1)*]**

Ans. Net capacitance in series combination is given by

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} \quad \Rightarrow \quad \frac{1}{C_s} = \frac{1}{12} + \frac{1}{12}$$

$$\Rightarrow \quad C_s = 6 \text{ pF}$$

$$E_s = \frac{1}{2}C_s V^2 = \frac{1}{2} \times 6 \times 10^{-12} \times 50 \times 50$$

$$= 7500 \times 10^{-12} \text{ J}$$

$$= 7.5 \times 10^{-9} \text{ J}$$

Net capacitance in parallel combination is given by

$$C_p = 12 \text{ pF} + 12 \text{ pF} = 24 \text{ pF}$$

$$E_p = \frac{1}{2}C_p V^2 = \frac{1}{2} \times 24 \times 10^{-12} \times 50 \times 50$$

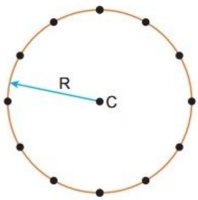
$$= \mathbf{3 \times 10^{-8} \text{ J}}$$

Short Answer Questions

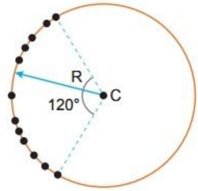
Each of the following questions are of 3 marks.

Q. 1. **(*a*) Twelve negative charges of same magnitude are equally spaced and fixed on the circumference of a circle of radius R as shown in Fig. (*i*). Relative to potential being zero at infinity, find the electric potential and electric field at the center C of the circle.**

(*b*) If the charges are unequally spaced and fixed on an arc of 120° of radius R as shown in Fig. (*ii*), find electric potential at the centre C. [*CBSE 2023 (55/1/1)*]



(i)



Ans. (*a*) Potential due to single charge at C, $V = \dfrac{kq}{r_1}$

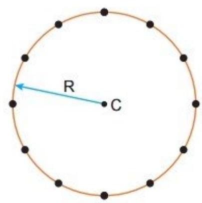
Here, $q_1 = q_2 = \ldots\ldots = q_{12} = -q$ and $r_1 = r_2 = \ldots\ldots r_{12} = R$

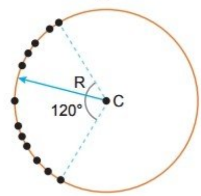
So, net electric potential at C,

$$V_C = V_1 + V_2 + \ldots\ldots + V_{12}$$

$$= -kq\left[\frac{1}{R}\times 12\right]$$

$$= -\frac{\mathbf{12kq}}{\mathbf{R}}.$$





Due to symmetry of distribution of charges.

All electric fields are cancel to each other.

So, $E = \mathbf{0}$

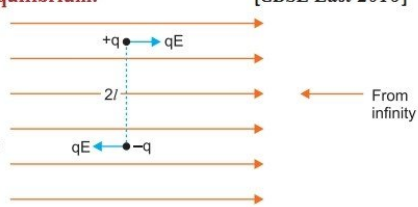
(*b*) Potential is a scalar and orientation is irrelevant.

Hence, Net potential at C,

$$V_C = -\frac{\mathbf{12kq}}{\mathbf{R}}.$$

Q. 2. **Show that the potential energy of a dipole making angle θ with the direction of the field is given by $U(\theta) = -\vec{P}\cdot\vec{E}$. Hence find out the amount of work done in rotating it from the position of unstable equilibrium to the stable equilibrium.** [*CBSE East 2016*]

Ans. The potential energy of an electric dipole in an electric field is defined as the work done in bringing the dipole from infinity to its present position in the electric field.



Suppose the dipole is brought from infinity and placed at orientation θ with the direction of electric field. The work done in this process may be supposed to be done in two parts.

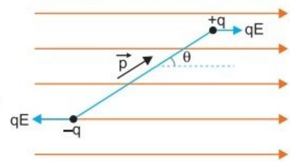
(*i*) The work done (W_1) in bringing the dipole perpendicular to electric field from infinity.

(*ii*) Work done (W_2) in rotating the dipole such that it finally makes an angle θ from the direction of electric field.

Let us suppose that the electric dipole is brought from infinity in the region of a uniform electric field such that its dipole moment $\vec{P}$ always remains perpendicular to electric field. The electric forces on charges $+q$ and $-q$ are qE and $-qE$, along the field direction and opposite to field direction respectively.

As charges $+q$ and $-q$ traverse equal distance under equal and opposite forces; therefore, net work done in bringing the dipole in the region of electric field perpendicular to field-direction will be zero, *i.e.*, $W_1 = 0$.

Now the dipole is rotated and brought to orientation making an angle θ with the field direction (*i.e.*, $\theta_0 = 90°$ and $\theta_1 = \theta$), therefore, work done



$$W_2 = pE\ (\cos\theta - \cos\theta_1)$$

$$= pE\ (\cos 90° - \cos\theta) = -pE\cos\theta$$

$\therefore$ Total work done in bringing the electric dipole from infinity, *i.e.*,

Electric potential energy of electric dipole

$$U = W_1 + W_2 = 0 - pE\cos\theta = -pE\cos\theta$$

In vector form $U = -\vec{p}\cdot\vec{E}$

For rotating dipole from position of unstable equilibrium ($\theta_0 = 180°$) to the stable equilibrium ($\theta = 0°$)

$$\therefore \quad W_{req} = pE(\cos 180° - \cos 0°)$$

$$= pE(-1-1) = -\mathbf{2}\boldsymbol{pE}$$

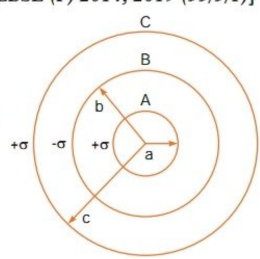
Q. 3. Three concentric metallic shells *A*, *B* and *C* of radii *a*, *b* and *c* ($a < b < c$) have surface charge densities $+\sigma$, $-\sigma$ and $+\sigma$ respectively as shown in the figure.
If shells *A* and *C* are at the same potential, then obtain the relation between the radii *a*, *b* and *c*.

[*CBSE (F) 2014, 2019 (55/5/1)*]

Ans. Charge on shell A, $q_A = 4\pi a^2\sigma$

Charge on shell B, $q_B = -4\pi b^2\sigma$

Charge of shell C, $q_C = 4\pi c^2\sigma$



Potential of shell A: Any point on the shell A lies inside the shells B and C.

$$V_A = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_A}{a} + \frac{q_B}{b} + \frac{q_C}{c}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{4\pi a^2\sigma}{a} - \frac{4\pi b^2\sigma}{b} + \frac{4\pi c^2\sigma}{c}\right]$$

$$= \frac{\sigma}{\varepsilon_0}(a - b + c)$$

Any point on B lies outside the shell A and inside the shell C. Potential of shell B,

$$V_B = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_A}{b} + \frac{q_B}{b} + \frac{q_C}{c}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{4\pi a^2\sigma}{b} - \frac{4\pi b^2\sigma}{b} + \frac{4\pi c^2\sigma}{c}\right] = \frac{\sigma}{\varepsilon_0}\left[\frac{a^2}{b} - b + c\right]$$

Any point on shell C lies outside the shells A and B. Therefore, potential of shell C.

$$V_C = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_A}{c} + \frac{q_B}{c} + \frac{q_C}{c}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{4\pi a^2\sigma}{c} - \frac{4\pi b^2\sigma}{c} + \frac{4\pi c^2\sigma}{c}\right]$$

$$= \frac{\sigma}{\varepsilon_0}\left[\frac{a^2}{c} - \frac{b^2}{c} + c\right]$$

Now, we have

$$V_A = V_C$$

$$\frac{\sigma}{\varepsilon_0}(a - b + c) = \frac{\sigma}{\varepsilon_0}\left(\frac{a^2}{c} - \frac{b^2}{c} + c\right)$$

$$a - b = \frac{(a-b)(a+b)}{c}$$

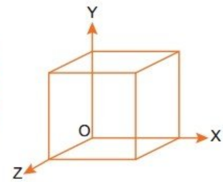
or $\quad \boldsymbol{a + b = c}$

Q. 4. A cube of side 20 cm is kept in a region as shown in the figure. An electric field $\vec{E}$ exists in the region such that the potential at a point is given by $V = 10x + 5$, where V is in volt and x is in m. ***[CBSE 2020 (55/2/1)]***

Find the

(*i*) electric field, and

(*ii*) total electric flux through the cube.



Ans. (*i*) We have, $E = -\frac{dV}{dx} = -\frac{d}{dx}(10x + 5)$ **1**

$\therefore \quad \boldsymbol{\vec{E} = -10\,\hat{i}}$ **N/C** **½**

(*ii*) Electric flux through the cube, ϕ = sum of electric flux through 6 faces.

Electric flux through perpendicular Y and Z axis = 0 **½**

$\because$ E is along x axis

Electric flux through faces perpendicular to x – axis, **½**

$$\phi = \phi_1 + \phi_2$$ **½**

$$= 10 \times (0.2)^2 - 10 \times (0.2)^2 = 0$$ ***[CBSE Marking Scheme 2020 (55/2/1)]***

Q. 5. A 600 pF capacitor is charged by a 200 V supply. It is then disconnected from the supply and is connected to the another uncharged 600 pF capacitor. How much electrostatic energy is lost in the process? ***[NCERT]***

Ans. Given, $C_1 = 600 \text{ pF} = 600 \times 10^{-12}$ F, $V_1 = 200$ V

Initial energy stored, $U_{initial} = \frac{1}{2}C_1V_1^2 = \frac{1}{2} \times 600 \times 10^{-12} \times (200)^2 = 12 \times 10^{-6}$ J

When another uncharged capacitor C_2=600 pF is connected across capacitor C_1 then common potential difference

$$V = \frac{q_1 + q_2}{C_1 + C_2} = \frac{C_1V_1 + 0}{C_1 + C_2} = \frac{C_1V_1}{C_1 + C_2}$$

$$= \frac{600 \times 10^{-12} \times 200}{(600 + 600) \times 10^{-12}} = 100 \text{ V}$$

$\therefore$ Final electrostatic energy, $U_{\text{final}} = \frac{1}{2}(C_1 + C_2)V^2 = \frac{1}{2}(600 + 600) \times 10^{-12} \times (100)^2 = 6 \times 10^{-6}$ J

$\therefore$ Energy lost, $\Delta U = U_{\text{initial}} - U_{\text{final}} = 12 \times 10^{-6} - 6 \times 10^{-6} = \boldsymbol{6 \times 10^{-6}}$ **J**

Q. 6. A parallel plate capacitor (*A*) of capacitance *C* is charged by a battery to voltage *V*. The battery is disconnected and an uncharged capacitor (*B*) of capacitance 2*C* is connected across *A*. Find the ratio of ***[CBSE 2023 (55/2/1)]***

(*i*) final charges on *A* and *B*.

(*ii*) total electrostatic energy stored in *A* and *B* finally and that stored in *A* initially.

Ans. (*i*) Total charge on A, $q_A = CV$

After nn with capacitor B,

$$V_{\text{common}} = \frac{q_A + q_B}{C_A + C_B} = \frac{CV}{2C + C} = \frac{V}{3}$$

Now, final charge , $q'_A = C\left(\frac{V}{3}\right) = \frac{CV}{3}$

and $$q'_B = 2C\left(\frac{V}{3}\right) = \frac{2CV}{3}$$

So, Ratio, $$\frac{q'_A}{q'_B} = \frac{\frac{CV}{3}}{\frac{2CV}{3}} = \mathbf{\frac{1}{2}}$$

(*ii*) Initial energy stored on A,

$$U_A = \frac{1}{2}CV^2$$

Now, finally energy stored on A and B both,

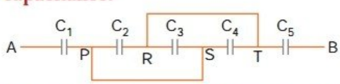
$$E_T = E_A + E_B$$

$$= \frac{1}{2}C\left(\frac{V}{3}\right)^2 + \frac{1}{2}2C\left(\frac{V}{3}\right)^2$$

$$= \frac{1}{2}3C\left(\frac{V^2}{q}\right) = \frac{CV^2}{6} = \frac{U_A}{3}$$

Now, Ratio, $$\frac{U_T}{U_A} = \frac{\frac{U_A}{3}}{U_A} = \mathbf{\frac{1}{3}}$$

Q. 7. (*i*) Find equivalent capacitance between A and B in the combination given below. Each capacitor is of 2 μF capacitance.



(*ii*) If a dc source of 7 V is connected across *AB*, how much charge is drawn from the source and what is the energy stored in the network? **[*CBSE Delhi 2017*]**

Ans. (*i*) Capacitors C_2, C_3 and C_4 are in parallel

$$C_{234} = C_2 + C_3 + C_4 = 2\ \mu\text{F} + 2\ \mu\text{F} + 2\ \mu\text{F}$$

$$\therefore \quad C_{234} = 6\ \mu\text{F}$$

Capacitors C_1, C_{234} and C_5 are in series,

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_{234}} + \frac{1}{C_5} = \frac{1}{2} + \frac{1}{6} + \frac{1}{2}$$

$$= \frac{7}{6}$$

$$\therefore C_{eq} = \mathbf{\frac{6}{7}\ \mu F}$$

(*ii*) Charge drawn from the source

$$Q = C_{eq}V$$

$$= \frac{6}{7} \times 7\ \mu\text{C} = \mathbf{6\ \mu C}$$

Energy stored in the network, $U = \dfrac{Q^2}{2C} = \dfrac{6 \times 6 \times 10^{-12} \times 7}{2 \times 6 \times 10^{-6}} \text{J}$

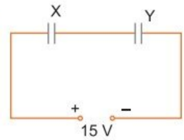
$$= 21 \times 10^{-6}\ \text{J} = \mathbf{21\ \mu J}$$

Q. 8. Two parallel plate capacitors *X* and *Y* have the same area of plates and same separation between them. *X* has air between the plates while *Y* contains a dielectric medium $\varepsilon_r = 4$.

(i) Calculate the capacitance of each capacitor if equivalent capacitance of the combination is 4 μF.

(ii) Calculate the potential difference between the plates of *X* and *Y*.

(iii) Estimate the ratio of electrostatic energy stored in *X* and *Y*.



[*CBSE Delhi 2016*]

Ans. (i) Capacitance of X, $C_X = \dfrac{\varepsilon_0 A}{d}$

Capacitance of Y, $C_Y = \dfrac{\varepsilon_r \varepsilon_0 A}{d} = 4\dfrac{\varepsilon_0 A}{d}$

$$\therefore \quad \frac{C_Y}{C_X} = 4 \Rightarrow C_Y = 4C_X \quad \ldots(i)$$

As X and Y are in series, so

$$C_{eq} = \frac{C_X C_Y}{C_X + C_Y} \Rightarrow 4\ \mu\text{F} = \frac{C_X . 4C_X}{C_X + 4C_X}$$

$$\Rightarrow \quad C_X = \mathbf{5\ \mu F} \text{ and } C_Y = 4C_X = \mathbf{20\ \mu F}$$

(ii) In series charge on each capacitor is same, so

$$\text{P.d. } V = \frac{Q}{C} \Rightarrow V \propto \frac{1}{C}$$

$$\therefore \quad \frac{V_X}{V_Y} = \frac{C_Y}{C_X} = 4 \Rightarrow V_X = 4V_Y \quad \ldots(ii)$$

Also $\quad V_X + V_Y = 15 \quad \ldots(iii)$

From (ii) and (iii),

$$4V_Y + V_Y = 15 \Rightarrow V_Y = 3\ \text{V}$$
$$V_X = 15 - 3 = 12\ \text{V}$$

Thus potential difference across X, V_X **= 12 V,** P.d. across Y, V_Y **= 3 V**

(iii) $$\frac{\text{Energy stored in } X}{\text{Energy stored in } Y} = \frac{Q^2/2C_X}{Q^2/2C_Y} = \frac{C_Y}{C_X} = \frac{4}{1} \Rightarrow \frac{U_X}{U_Y} = \mathbf{\frac{4}{1}}$$

Q. 9. A capacitor of 4 μF is charged by a battery of 12 V. The battery is disconnected and a dielectric slab of dielectric constant 8 is inserted in between the plates of the capacitor of fill the space completely. Find the change in the (*a*) charge stored in the capacitor, (*b*) potential difference between the places of the capacitor, and (*c*) energy stored in the capacitor. [*CBSE 2020 (55/2/3)*]

Ans. (a) Charge, $q = CV = 48 \times 10^{-6}$ C ½

Charge remains same or no change. ½

(b) Initial potential difference, $V_0 = 12$ V

After battery is removed,

$$V = \frac{V_0}{K} = \frac{12}{8} = 1.5 \text{ volt} \quad ½$$

Decrease in potential difference = 12 – 1.5 = 10.5 V ½

(c) Energy stored initially,

$$U_0 = \frac{1}{2}C_0 V_0^2 = \frac{1}{2} \times 4 \times 10^{-6} \times 12 \times 12 = 288 \times 10^{-6}\text{J} \quad ½$$

Final energy stored, $U = \frac{1}{2}CV^2 = \frac{1}{2}C_0\frac{V_0^2}{K} = \frac{1}{2}\times\frac{4\times10^{-6}\times12\times12}{8} = 36\times10^{-6}$J

$\therefore$ Energy reduces, $\Delta U = U_0 - U = (288-36)\times10^{-6}$ J $= 252\times10^{-6}$ J ½

Note : (*b*) Even if a student writes, voltage becomes $\frac{1}{8}$ award full one mark.

(*c*) Even if a student, without evaluating U_o and U, writes U becomes $\frac{1}{k}$, award $\frac{1}{2}$ mark; and award $\frac{1}{2}$ mark for the correct formulae for U and U_o

[CBSE Marking Scheme 2020 (55/2/3)]

Q. 10. A 200 μF parallel plate capacitor having plate separation of 5 mm is charged by a 100 V *dc* source. It remains connected to the source. Using an insulated handle, the distance between the plates is doubled and a dielectric slab of thickness 5 mm and dielectric constant 10 is introduced between the plates. Explain with reason, how the (*i*) capacitance, (*ii*) electric field between the plates, (*iii*) energy density of the capacitor will change? *[CBSE 2019 (55/2/1)]*

Ans. Dielectric slab of thickness 5 mm is equivalent to an air capacitor of thickness = $\frac{5}{10}$ mm.

Effective separation between the plates with air in between is = (5 + 0.50) mm = 5.5 mm

(*i*) Effective new capacitance,

$$C' = 200\,\mu\text{F}\times\frac{5\text{ mm}}{5.5\text{ mm}} = \frac{2000}{11}\mu\text{F}$$

$$\approx \mathbf{182\,\mu F}$$

(*ii*) Effective new electric field,

$$E' = \frac{100\,V}{5.5\times10^{-3}\text{m}} = \frac{200000}{11}\text{V/m, where } E = \frac{V}{d} = \frac{100}{5\times10^{-3}} = 20000 \text{ V/m}$$

$$\approx \mathbf{18182\ V/m}$$

(*iii*) $$\frac{\text{New energy density}}{\text{Original energy density}} = \frac{\frac{1}{2}\varepsilon_0 E'^2}{\frac{1}{2}\varepsilon_0 E^2} = \left(\frac{E'}{E}\right)^2 = \left(\frac{10}{11}\right)^2$$

New Energy density will be $\left(\frac{10}{11}\right)^2$ of the original energy density = $\mathbf{\frac{100}{121}}$ the original energy density.

Q. 11. In a parallel plate capacitor with air between the plates, each plate has an area of 6×10^{-3} m^2 and the distance between the plates is 3 mm. Calculate the capacitance of the capacitor. If this capacitor is connected to a 100 V supply, what is the charge on each plate of the capacitor? *[NCERT] [HOTS]*

Ans. Capacitance of parallel plate air capacitor,

$$C = \frac{\varepsilon_0 A}{d}$$

Given $A = 6\times10^{-3}$ m^2, d = 3 mm = 3×10^{-3} m, $\varepsilon_0 = 8.85\times10^{-12}$ F/m.

$$\therefore \quad C = \frac{\varepsilon_0 A}{d} = \frac{8.85\times10^{-12}\times6\times10^{-3}}{3\times10^{-3}} = \mathbf{17.7\times10^{-12}\ F}$$

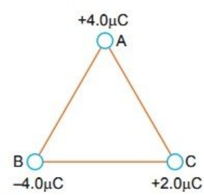
Charge on each plate of capacitor,

$$Q = CV = 17.7\times10^{-12}\times100 = 1.77\times10^{-9}\text{ coulomb} = \mathbf{1.77\ nC}$$

Q. 12. State the significance of negative value of electrostatic potential energy of a system of charges.

Three charges are placed at the corners of an equilateral triangle ABC of side 2.0 m as shown in figure. Calculate the electric potential energy of the system of three charges.

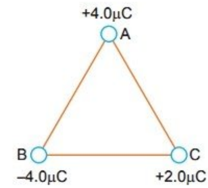
[CBSE, 2023] [55/2/1]



Ans. Negative value of electrostatic potential energy of a system signifies that the system has attractive forces.

Potential energy due to between two charges,

$$U = \frac{1}{4\pi \in_0} \times \frac{q_1 q_2}{r}$$



P.E due to system of three charges,

$$U = \frac{1}{4\pi \in_0}\left[\frac{q_A q_B}{r} + \frac{q_B q_C}{r} + \frac{q_C q_A}{r}\right]$$

$$= \frac{9\times 10^9}{2}[-16-8+8]\times 10^{-12}$$

$$= \mathbf{-7.2 \times 10^{-2}\ J}$$

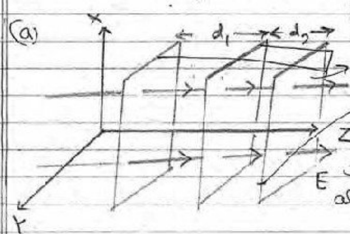
Q. 13. **(a) Draw equipotential surfaces corresponding to the electric field that uniformly increases in magnitude along with the *z*-directions.**

(b) Two charges –*q* and +*q* are located at point (0, 0, –*a*) and (0, 0, *a*). What is the electrostatic potential at the points (0, 0, ± *z*) and (*x*, *y*, 0)? **[*CBSE 2019 (55/1/2)*]**

Ans.

towards right.

(a)



(Parallel to ~~Along~~ x-y plane)

Plane surface (equipotential surfaces)

Also, $d_2 < d_1$ as electric field is uniformly increasing along the z-direction (axis)

(b) Electrostatic potential at point $(x, y, 0)$ is zero because it is lying on the equitorial plane of the dipole and is equidistant from both $+q$ and $-q$.

(0,0,-z)   -q (0,0,-a)   q (0,0,a)   (0,0,+z)

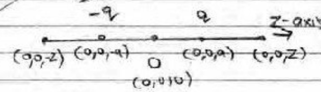
Now, potential at (0, 0, +z)

$$V_{+z} = V_q + V_{-q} = \frac{1}{4\pi\varepsilon_0}\frac{q}{(z-a)} + \frac{1}{4\pi\varepsilon_0}\frac{(-q)}{(z+a)}$$

$$V_{+z} = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{z-a} - \frac{1}{z+a}\right]$$

$$V_{+z} = \frac{q}{4\pi\varepsilon_0}\left[\frac{z+a-z+a}{z^2-a^2}\right]$$

$$V_{+z} = \frac{2qa}{4\pi\varepsilon_0(z^2-a^2)}$$



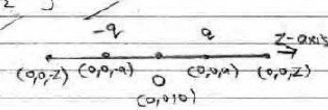
and $V_{-z} = V_{-q} + V_q$

$$= \frac{-q}{4\pi\varepsilon_0(z-a)} + \frac{q}{4\pi\varepsilon_0}\frac{1}{(z+a)}$$

$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{z+a} - \frac{1}{z-a}\right]$$

$$V_{+z} = \frac{q}{4\pi\varepsilon_0}\left[\frac{z+a-z+a}{z^2-a^2}\right]$$

$$V_{+z} = \frac{2qa}{4\pi\varepsilon_0(z^2-a^2)}$$



and $V_{-z} = V_{-q} + V_q$

$$= \frac{-q}{4\pi\varepsilon_0(z-a)} + \frac{q}{4\pi\varepsilon_0}\frac{1}{(z+a)}$$

$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{z+a} - \frac{1}{z-a}\right]$$

$$= \frac{q}{4\pi\varepsilon_0}\frac{(-2a)}{(z^2-a^2)} = \frac{-2qa}{4\pi\varepsilon_0(z^2-a^2)}$$

Hence, electrostatic potential at point (0,0,z) is $\frac{1}{4\pi\varepsilon_0}\frac{2qa}{z^2-a^2}$

and at (0,0,-z) is $-\frac{1}{4\pi\varepsilon_0}\frac{2qa}{z^2-a^2}$ **[*Toppers Answer 2019*]**

Q. 14. Two capacitors of capacitance 10 μF and 20 μF are connected in series with a 6 V battery. After the capacitors are fully charged, a slab of dielectric constant (*K*) is inserted between the plates of the two capacitors. How will the following be affected after the slab is introduced:

(*a*) the electric field energy stored in the capacitors?

(*b*) the charges on the two capacitors?

(*c*) the potential difference between the plates of the capacitors?

Justify your answer. **[*CBSE Bhubaneshwer 2015*]**

Ans. Let Q be the charge on each capacitor. So, $Q = \frac{C_1 C_2}{C_1 + C_2}V$.

Initial electric field energy in each capacitor becomes

$$U_1 = \frac{1}{2}\frac{Q^2}{C_1} \text{ and } U_2 = \frac{1}{2}\frac{Q^2}{C_2}$$

Initial charge on each capacitor

$$Q = C_1 V_1,\ \ Q = C_2 V_2 \text{ and } Q = \frac{C_1 C_2}{C_1 + C_2}.V$$

where V_1 and V_2 are *p.d* across the capacitors

On inserting the dielectric slab the capacitance of each capacitor becomes

$$C'_1 = KC_1 \text{ and } C'_2 = KC_2$$

and equivalent capacitance becomes

$$C'_{eq} = \frac{KC_1 \times KC_2}{KC_1 + KC_2} = K\frac{C_1 C_2}{C_1 + C_2}$$

New charge on the capacitor becomes

$$Q' = C'_{eq}V' = K\left(\frac{C_1 C_2}{C_1 + C_2}\right) \times V$$

$$Q' = \frac{C_1 C_2}{C_1 + C_2}.V \times K$$

$$Q' = Q \times K$$

$$Q' = KQ$$

(*a*) New electric field energy becomes

$$U'_1 = \frac{Q'^2}{2KC_1} = \frac{KQ^2}{2C_1}$$

$$U'_2 = \frac{1}{2}\frac{Q'^2}{KC_2} = \frac{KQ^2}{2C_2}$$

i.e., electric field energy increases in each capacitor.

(*b*) $Q' = KQ$ (as stated above) *i.e.*, charges are increases on each capacitor.

(*c*) $$V'_1 = \frac{Q'}{C_1'} = \frac{KQ}{KC_1} = \frac{Q}{C_1}$$

and $$V'_2 = \frac{Q'}{C_2'} = \frac{KQ}{KC_2} = \frac{Q}{C_2}$$

i.e., *p.d* across each capacitor remains same.

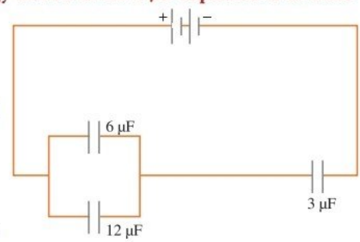
Q. 15. In the following arrangement of capacitors, the energy stored in the 6 μF capacitor is E. Find the value of the following:

(*i*) Energy stored in 12 μF capacitor.

(*ii*) Energy stored in 3 μF capacitor.

(*iii*) Total energy drawn from the battery.

[*CBSE (F) 2016*]



Ans. Given that energy stored in 6 μF is E.

(*i*) Let V be the voltage across 6 μF capacitor

Also, 6 μF and 12 μF capacitors are in parallel.

Therefore, voltage across 12 μF = Voltage across 6 μF capacitor

$$E = \frac{1}{2}CV^2 = \frac{1}{2}\times 6\times V^2 \quad \Rightarrow \quad V = \sqrt{\frac{E}{3}}$$

$$\text{Energy stored in } 12\mu\text{F} = \frac{1}{2}\times 12\times\left(\sqrt{\frac{E}{3}}\right)^2 = \mathbf{2E}$$

(*ii*) Since charge remains constant in series. Sum of charge on 6 μF capacitor and 12 μF capacitor is equal to charge on 3 μF capacitor.

Using $Q = CV$,

Charge on 3 μF capacitor = $(6 + 12) \times V = 18V$

$$\text{Energy stored in 3 F capacitor} = \frac{Q^2}{2C} = \frac{(18V)^2}{2\times 3} = \frac{18\times 18}{6}\left(\frac{\sqrt{E}}{3}\right)^2 = \mathbf{18\,E}$$

(*iii*) Total energy drawn from battery = $E + 2E + 18E$ = $\mathbf{21E}$

Q. 16. In the figure given below, find the

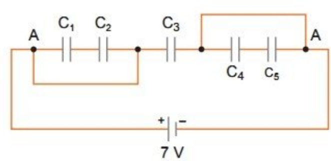
(*a*) equivalent capacitance of the network between points A and B.

Given: $C_1 = C_5 = 8$ μF, $C_2 = C_3 = C_4 = 4$ μF.

(*b*) maximum charge supplied by the battery, and

(*c*) total energy stored in the network.

[*CBSE 2020 (55/2/1)*]

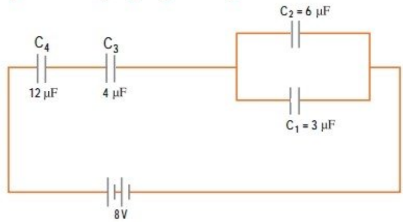


Ans. (*a*) Equivalent Capacitance, $C = C_4 = \mathbf{4\,\mu F}$ (as C_1, C_2, C_4, C_5 are short circuited)

(*b*) Charge, $Q = CV = 4 \times 7\ \mu\text{C} = \mathbf{28\ \mu C}$

(*c*) Energy stored, $U = \frac{1}{2}CV^2 = \frac{1}{2}\times 4\times 10^{-6}\times 7\times 7 = \mathbf{98\times 10^{-6} J}$

Q. 17. In a network, four capacitors C_1, C_2, C_3 and C_4 are connected as shown in the figure.



(a) Calculate the net capacitance in the circuit.

(b) If the charge on the capacitor C_1 is 6 μC, (i) calculate the charge on the capacitors C_3 and C_4, and (ii) net energy stored in the capacitors C_3 and C_4 connected in series.

[*CBSE 2019 (55/2/3)*]

Ans. (a) Capacitance across C_3 & C_4

$$C_{34} = \frac{12\times 4}{16} = 3\,\mu\text{F}$$

Capacitance across C_2 & C_1

$$C_{12} = 6+3 = 9\,\mu\text{F}$$

Equivalent capacitance **1**

$$C_{eq} = \frac{9\times 3}{12} = \frac{9\,\mu\text{F}}{4}$$

(b) (i) $Q_1 = 6\,\mu C,\ V_1 = \dfrac{Q_1}{C_1}$

$$= \frac{6\times 10^{-6}}{3\times 10^{-6}} = 2\text{ V}$$

$\therefore Q_2 = C_2 V_1 = 6\times 10^{-6}\times 2 = 12\,\mu C$ **1**

As C_3 & C_4 are in series they carry a charge of $18\,\mu C$ each

(ii) $Q = 18\,\mu\text{C}$

$C_{43} = 3\,\mu\text{F}$

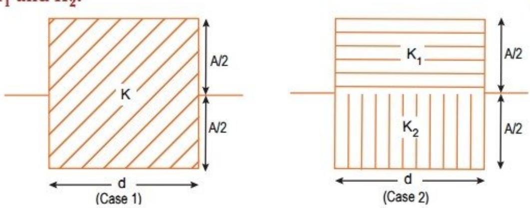
$$E_{34} = \frac{1}{2}\frac{Q^2}{C_{34}}$$ **½**

$$= \frac{1}{2}\times\frac{(18\times 10^{-6})^2}{3\times 10^{-6}}$$ **½**

$\therefore E_{34} = 54\times 10^{-6}$ joule

[*CBSE Marking Scheme 2019 (55/2/3)*]

Q. 18. The space between the plates of a parallel plate capacitor is completely filled in two ways. In the first case, it is filled with a slab of dielectric constant K. In the second case, it is filled with two slabs of equal dimensions but dielectric constants K_1 and K_2, respectively as shown in the figure. The capacitance of the capacitor is same in the two cases. Obtain the relationship between K, K_1 and K_2. **[*CBSE 2020 (55/1/3)*]**



Ans. **Case I:** Let area of each plate = A

and initially capacitance of parallel plate capacitor, $C_1 = \dfrac{\varepsilon_0 A}{d}$

After inserting respective dielectric slabs, we have $C_1 = \dfrac{K\varepsilon_0 A}{d}$

Case II: It is filled with two slabs of equal dimension with dielectric constants K_1 and K_2 respectively in given such a way. So, it behave as capacitors are connected in parallel.

C_2 = parallel combination of two capacitors.

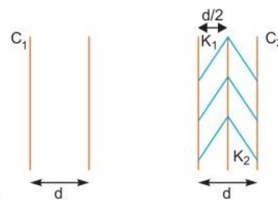
$$= \frac{K_1\varepsilon_0(A/2)}{d} + \frac{K_2\varepsilon_0(A/2)}{d} = \frac{\varepsilon_0 A}{2d}(K_1 + K_2)$$

$$\because \quad C_1 = C_2 \text{ (given)} \Rightarrow K = \boldsymbol{\frac{K_1 + K_2}{2}}$$

Q. 19. You are given an air filled parallel plate capacitor C_1. The space between its plates is now filled with slabs of dielectric constants K_1 and K_2 as shown in C_2. Find the capacitances of the capacitor C_2 if area of the plates is A and distance between the plates is d.

[*HOTS*] [*CBSE (F) 2011*]

Ans. Capacitance, $C_1 = \dfrac{\varepsilon_0 A}{d}$

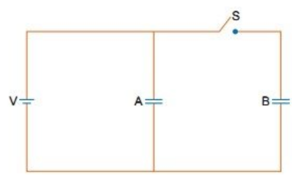


It is filled with two slabs of with dielectric constants K_1 and K_2 respectively as given such a way. Hence, it behave as capacitors are connected in series. So,

$$\frac{1}{C_2} = \frac{1}{K_1\dfrac{\varepsilon_0 A}{d/2}} + \frac{1}{K_2\dfrac{\varepsilon_0 A}{d/2}} = \frac{d}{2.K_1\varepsilon_0 A} + \frac{d}{2.K_2\varepsilon_0 A}$$

$$\Rightarrow \frac{1}{C_2} = \frac{d}{2\varepsilon_0 A}\left[\frac{1}{K_1} + \frac{1}{K_2}\right] \Rightarrow C_2 = \frac{2.\varepsilon_0 A}{d}\left[\frac{K_1K_2}{K_1 + K_2}\right] = \boldsymbol{C_1\left[\frac{2K_1K_2}{K_1 + K_2}\right]}$$

Q. 20. Two identical parallel plate capacitors A and B are connected to a battery of V volts with the switch S closed. The switch is now opened and the free space between the plates of the capacitors is filled with a dielectric of dielectric constant K. Find the ratio of the total electrostatic energy stored in both capacitors before and after the introduction of the dielectric. **[*CBSE (AI) 2017*]**



Ans.

19. Initially:

$C_A^0 = \dfrac{\varepsilon_0 A}{d} = C \quad V_0$

$C_B^0 = \dfrac{\varepsilon_0 A}{d} = C \quad . \quad V_0.$

Later

$C_A = K C_A^0 = KC$

$C_B = KC.$

Total electrostatic energy

stored before dielectric

is $\frac{1}{2} C_A V_A^2 + \frac{1}{2} C_B V_B^2$

$\frac{1}{2} \times CV^2 + \frac{1}{2} CV^2$

$\times 2 \times \frac{1}{2} CV^2 = \underline{\underline{CV^2}}$

After across A

$\frac{1}{2} \times C_A \cdot V^2$

$\frac{1}{2} \times KC \times V^2$

$= K \times \frac{1}{2} \underline{\underline{CV^2}}$

across B $\quad \frac{1}{2} C_B \times V_{new}^2$

$\frac{1}{2} C_B \times \frac{V_0^2}{K^2} = \frac{1}{2} \times KC \times \frac{V_0^2}{K^2}$

$\frac{1}{2} \frac{CV_0^2}{K} = \frac{1}{2} \frac{CV^2}{K}$

Total energy after insertion $= \frac{KCV^2}{2} + \frac{CV^2}{2K}$

$\frac{CV^2}{2}\left[K + \frac{1}{K}\right]$

$\frac{CV^2}{2}\left[\frac{K^2+1}{K}\right]$

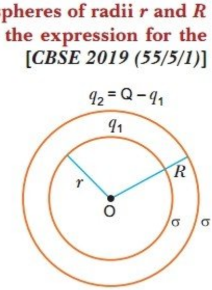
Ratio is $\frac{CV^2 \times 2K}{CV^2 (K^2+1)}$

$= \frac{2K}{K^2+1}$

[*Toppers Answer 2017*]

Q. 21. A charge Q is distributed over the surfaces of two concentric hollow spheres of radii r and R ($R >> r$), such that their surface charge densities are equal. Derive the expression for the potential at the common centre. [*CBSE 2019 (55/5/1)*]

Ans. If charge q_1 is distributed over the smaller sphere and q_2 over the larger sphere, then



$$Q = q_1 + q_2 \qquad ...(i)$$

If σ is the surface charge density of the two spheres, then

$$\sigma = \frac{q_1}{4\pi r^2} = \frac{q_2}{4\pi R^2}$$

or $\qquad q_1 = 4\pi r^2 \sigma \quad$ and $\quad q_2 = 4\pi R^2 \sigma$

From (*i*), we have

$$Q = 4\pi r^2\sigma + 4\pi R^2\sigma$$

$$= 4\pi\sigma(r^2 + R^2)$$

or $$\sigma = \frac{Q}{4\pi(r^2 + R^2)}$$

The potential at a point inside the charged sphere is equal to the potential at its surface. So, the potential due to the smaller sphere at the common centre,

$$V_1 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1}{r}$$

Also, the potential due to the larger sphere at the common centre,

$$V_2 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_2}{\text{R}}$$

$\therefore$ Potential at common centre,

$$V = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1}{r} + \frac{q_2}{R}\right)$$

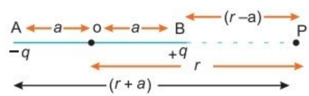
$$= \frac{1}{4\pi\varepsilon_0} \times \left[\frac{4\pi r^2\sigma}{r} + \frac{4\pi R^2\sigma}{R}\right]$$

$$= \frac{(r+R)\sigma}{\varepsilon_0} = \frac{1}{4\pi\varepsilon_0}\left[\frac{Q(r+R)}{r^2 + R^2}\right] \text{ (By putting the value of } \sigma)$$

Q. 22. (*a*) Derive an expression for the electric potential at any point along the axial line of an electric dipole.

(*b*) Find the electrostatic potential at a point on equatorial line of an electric dipole.

Ans. (*a*) Potential at point P



$$V_P = V_{-q} + V_{+q}$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{-q}{(r+a)} + \frac{1}{4\pi\varepsilon_0}\frac{q}{(r-a)}$$

$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{(r-a)} - \frac{1}{(r+a)}\right]$$

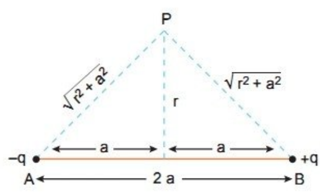
$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{r+a-r+a}{(r-a)(r+a)}\right]$$

$$= \frac{q}{4\pi\varepsilon_0} \times \frac{2a}{(r^2 - a^2)} = \frac{q \times 2a}{4\pi\varepsilon_0(r^2 - a^2)}$$

$$= \frac{1}{4\pi\varepsilon_0} \times \frac{p}{(r^2 - a^2)} \text{ (where } p \text{ is the dipole moment)}$$

For a short dipole, $a^2 << r^2$, so $V = V = \frac{1}{4\pi\varepsilon_0} \times \frac{p}{r^2}$

(*b*) Let P be a point on the equatorial line of an electric dipole due to charges $-q$ and $+q$ with separation $2a$



The distance of point P from centre of dipole = r

$$AP = BP = \sqrt{r^2 + a^2}$$

Electrostatic potential at P, $V_P = \frac{1}{4\pi\epsilon_0}\left(\frac{q}{BP}-\frac{q}{AP}\right)$

$$\Rightarrow \qquad V_P = \frac{1}{4\pi\epsilon_0}\left[\frac{q}{\sqrt{r^2+a^2}}-\frac{q}{\sqrt{r^2+a^2}}\right] = \mathbf{0}$$

That is electrostatic potential at each equatorial point of an electric dipole is **zero**.

Q. 23. If N drops of same size each having the same charge, coalesce to form a bigger drop. How will the following vary with respect to single small drop?

(*i*) Total charge on bigger drop

(*ii*) Potential on the bigger drop

(*iii*) Capacitance **[*CBSE Sample Paper 2017*]**

Ans. Let r, q and v be the radius, charge and potential of the small drop.

The total charge on bigger drop is sum of all charge on small drops.

(*i*) $\therefore \quad Q = \boldsymbol{Nq}$ (where Q is charge on bigger drop)

(*ii*) The volume of N small drops $= N\frac{4}{3}\pi r^3$

Volume of the bigger drop $= \frac{4}{3}\pi R^3$

Hence, $\quad N\frac{4}{3}\pi r^3 = \frac{4}{3}\pi R^3 \quad \Rightarrow \quad R = N^{1/3}r$

Potential on bigger drop, $V = \frac{1}{4\pi\varepsilon_0}\times\frac{Q}{R}$

$$= \frac{1}{4\pi\varepsilon_0}\frac{Nq}{N^{1/3}r} = \frac{1}{4\pi\varepsilon_0}\frac{N^{2/3}.q}{r}$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{q}{r}.N^{2/3} = \boldsymbol{N^{2/3}v} \quad \left[\therefore v = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}\right]$$

(*iii*) Capacitance $= 4\pi\varepsilon_0 R$

$= 4\pi\varepsilon_0 N^{1/3}r$

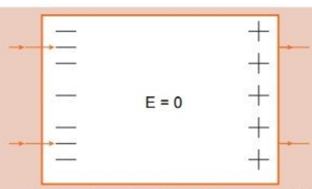
$= N^{1/3}\,(4\pi\varepsilon_0 r)$

$= \boldsymbol{N^{1/3}C}$ [where C is capacitance of the small drop]

Q. 24. (*a*) Explain briefly, using a proper diagram, the difference in behaviour of a conductor and a dielectric in the presence of external electric field.

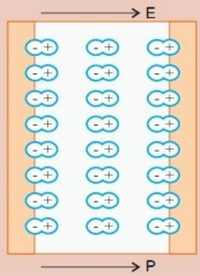
(*b*) Define the term polarization of a dielectric and write the expression for a linear isotropic dielectric in terms of electric field. **[*CBSE 2019 (55/3/1)*]**

Ans. ½



(*a*) **For conductor:** Due to induction the free electrons collect on the left face of slab creating equal positive charge on the right face. Internal electric field is equal and opposite to external field; hence net electric field (inside the conductor) is zero. ½

½



For dielectric: Due to alignment of atomic dipoles along $\vec{E}$, the net electric field within the dielectric decreases. ½

(*b*) The net dipole moment developed per unit volume in the presence of external electric field is called polarization vector $\vec{P}$. ½

Expression: $\vec{P} = \chi_e \vec{E}$ ½

[*CBSE Marking Scheme 2029 (55/3/1)*]

Long Answer Questions

Each of the following questions are of 5 marks.

Q. 1. Derive an expression for the electric potential at a point due to an electric dipole. Mention the contrasting features of electric potential of a dipole at a point as compared to that due to a single charge. [*CBSE Delhi 2008, 2017*]

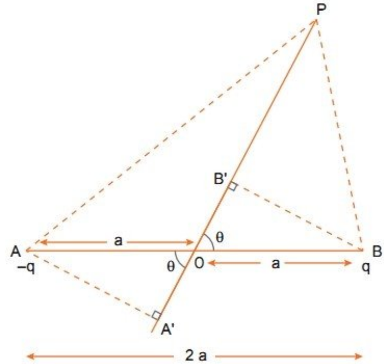
Ans. Potential at a point due to a dipole.

Suppose, the negative charge $-q$ is placed at a point A and the positive charge q is placed at a point B (fig.), the separation $AB = 2a$. The middle point of AB is O. The potential is to be evaluated at a point P where $OP = r$ and $\angle POB = \theta$. Also, let $r >> a$.

Let AA' be the perpendicular from A to PO and BB' be be the perpendicular from B to PO. Since a is very small compared to r,

$$AP = A'P = OP + OA'$$
$$= OP + AO\cos\theta$$
$$= r + a\cos\theta$$

Similarly, $BP = B'P = OP - OB'$
$$= r - a\cos\theta$$



The potential at P due to the charge $-q$ is

$$V_1 = -\frac{1}{4\pi\varepsilon_0}\frac{q}{AP} = -\frac{1}{4\pi\varepsilon_0}\frac{q}{r + a\cos\theta}$$

The potential at P due to the charge q is

$$V_2 = \frac{1}{4\pi\varepsilon_0}\frac{q}{BP} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r - a\cos\theta}$$

The net potential at P due to the dipole is

$$V = V_1 + V_2$$

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{r - a\cos\theta} - \frac{q}{r + a\cos\theta}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{q\,2a\cos\theta}{r^2 - a^2\cos^2\theta}$$

$$V = \frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{r^2}$$

Special Cases:

(*i*) When point P lies on the axis of dipole, then $\theta = 0°$

$\therefore \quad \cos\theta = \cos 0^0 = 1$

$\therefore \quad V = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^2}$

(*ii*) When point P lies on the equatorial plane of the dipole, then

$\therefore$ $\cos\theta = \cos 90° = 0$

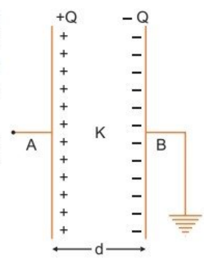
$\therefore \quad V = 0$

It may be noted that the electric potential at any point on the equitorial line of a dipole is zero.

Q. 2. Briefly explain the principle of a capacitor. Derive an expression for the capacitance of a parallel plate capacitor, whose plates are separated by a dielectric medium.

Ans. Principle of a Capacitor: A capacitor works on the principle that the capacitance of a conductor increases appreciably when an earthed conductor is brought near it.

Parallel Plate Capacitor: Consider a parallel plate capacitor having two plane metallic plates A and B, placed parallel to each other (see fig.). The plates carry equal and opposite charges $+Q$ and $-Q$ respectively.



In general, the electric field between the plates due to charges $+Q$ and $-Q$ remains uniform, but at the edges, the electric field lines deviate outward. If the separation between the plates is much smaller than the size of plates, the electric field strength between the plates may be assumed uniform.

Let A be the area of each plate, 'd' the separation between the plates, K the dielectric constant of medium between the plates. If σ is the magnitude of charge density of plates, then

$$\sigma = \frac{Q}{A}$$

The electric field strength between the plates

$$E = \frac{\sigma}{K\epsilon_0} \text{ where } \varepsilon_0 = \text{permittivity of free space.} \quad ...(i)$$

The potential difference between the plates, $V_{AB} = Ed = \frac{\sigma d}{K\varepsilon_0}$ ...(*ii*)

Putting the value of σ, we get

$$V_{AB} = \frac{(Q / A)d}{K\,\varepsilon_0} = \frac{Qd}{K\,\varepsilon_0 A}$$

$\therefore$ Capacitance of capacitor,

$$C = \frac{Q}{V_{AB}} = \frac{Q}{(Qd / K\varepsilon_0 A)} \text{ or } C = \frac{K\varepsilon_0 A}{d} \quad ...(iii)$$

This is a general expression for capacitance of parallel plate capacitor. Obviously, the capacitance is directly proportional to the dielectric constant of medium between the plates.

For air capacitor ($K=1$); capacitance $C = \dfrac{\varepsilon_0 A}{d}$. This is expression for the capacitance of a parallel plate air capacitor. It can be seen that the capacitance of parallel plate (air) capacitor is

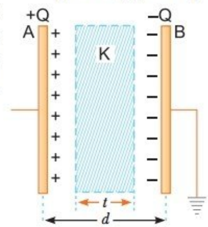
(*a*) directly proportional to the area of each plate.

(*b*) inversely proportional to the distance between the plates.

(*c*) independent of the material of the plates.

Q. 3. Derive an expression for the capacitance of a parallel plate capacitor when a dielectric slab of dielectric constant K and thickness $t = \dfrac{d}{2}$ but of same area as that of the plates is inserted between the capacitor plates. (d = separation between the plates). **[*CBSE (F) 2010*]**

Ans. Consider a parallel plate capacitor, area of each plate being A, the separation between the plates being d. Let a dielectric slab of dielectric constant K and thickness $t < d$ be placed between the plates. The thickness of air between the plates is $(d - t)$. If charges on plates are $+Q$ and $-Q$, then surface charge density $\sigma = \dfrac{Q}{A}$



The electric field between the plates in air, $E_1 = \dfrac{\sigma}{\varepsilon_0} = \dfrac{Q}{\varepsilon_0 A}$

The electric field between the plates in slab, $E_2 = \dfrac{\sigma}{K\varepsilon_0} = \dfrac{Q}{K\varepsilon_0 A}$

$\therefore$ The potential difference between the plates,

V_{AB} = work done in carrying unit positive charge from one plate to another

$= \Sigma Ex$ (as field between the plates is not constant).

$$= E_1(d-t) + E_2 t = \frac{Q}{\varepsilon_0 A}(d-t) + \frac{Q}{K\varepsilon_0 A}t$$

$$\therefore \quad V_{AB} = \frac{Q}{\varepsilon_0 A}\left[d - t + \frac{t}{K}\right]$$

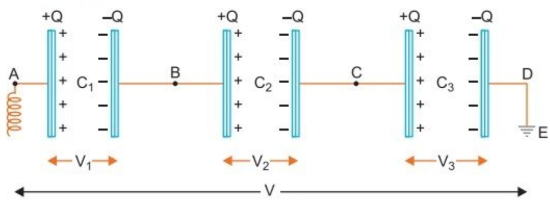
$$\therefore \quad \text{Capacitance of capacitor, } C = \frac{Q}{V_{AB}} = \frac{Q}{\dfrac{Q}{\varepsilon_0 A}\left(d - t + \dfrac{t}{K}\right)}$$

or,
$$C = \frac{\varepsilon_0 A}{d - t + \dfrac{t}{K}} = \frac{\varepsilon_0 A}{d - t\left(1 - \dfrac{1}{K}\right)}$$

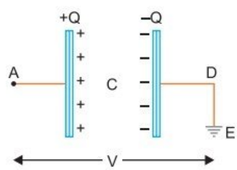
Here, $t = \dfrac{d}{2}$ $\quad\therefore\quad$ $C = \dfrac{\varepsilon_0 A}{d - \dfrac{d}{2}\left(1 - \dfrac{1}{K}\right)} = \dfrac{\varepsilon_0 A}{\dfrac{d}{2}\left(1 + \dfrac{1}{K}\right)}$

Q. 4. Derive an expression for equivalent capacitance of three capacitors when connected (*i*) in series and (*ii*) in parallel.

Ans. (*i*) In fig. (*a*) three capacitors of capacitances C_1, C_2, C_3 are connected in series between points A and D.



(a)



(b)

In series first plate of each capacitor has charge $+Q$ and second plate of each capacitor has charge $-Q$ *i.e.*, charge on each capacitor is Q.

Let the potential differences across the capacitors C_1, C_2, C_3 be V_1, V_2, V_3 respectively. As the second plate of first capacitor C_1 and first plate of second capacitor C_2 are connected together, their potentials are equal. Let this common potential be V_B. Similarly the common potential of second plate of C_2 and first plate of C_3 is V_C. The second plate of capacitor C_3 is connected to earth, therefore its potential $V_D = 0$. As charge flows from higher potential to lower potential, therefore $V_A > V_B > V_C > V_D$.

For the first capacitor, $V_1 = V_A - V_B = \dfrac{Q}{C_1}$ ...(*i*)

For the second capacitor, $V_2 = V_B - V_C = \dfrac{Q}{C_2}$ ...(*ii*)

For the third capacitor, $V_3 = V_C - V_D = \dfrac{Q}{C_3}$ ...(*iii*)

Adding (*i*), (*ii*) and (*iii*), we get

$$V_1 + V_2 + V_3 = V_A - V_D = Q\left[\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right] \quad \text{...(iv)}$$

If V be the potential difference between A and D, then

$$V_A - V_D = V$$

$\therefore$ From (*iv*), we get

$$V = (V_1 + V_2 + V_3) = Q\left[\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right] \quad \text{...(v)}$$

If in place of all the three capacitors, only one capacitor is placed between A and D such that on giving it charge Q, the potential difference between its plates become V, then it will be called **equivalent capacitor**. If its capacitance is C, then

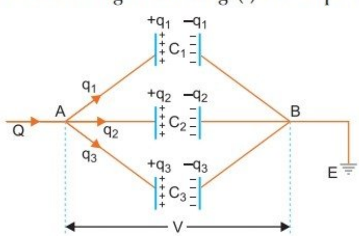
$$V = \frac{Q}{C} \quad \text{...(vi)}$$

Comparing (*v*) and (*vi*), we get

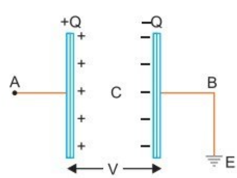
$$\frac{Q}{C} = Q\left[\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right] \quad \text{or} \quad \boldsymbol{\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

Thus in series arrangement, *"The reciprocal of equivalent capacitance is equal to the sum of the reciprocals of the individual capacitors."*

(*ii*) Parallel Arrangement: In fig. (*c*) three capacitors of capacitance C_1, C_2, C_3 are connected in parallel.



(c)



(d)

In parallel the potential difference across each capacitor is same V (say). Clearly the potential difference between plates of each capacitor

$$V_A - V_B = V \text{ (say)}$$

The charge Q given to capacitors is divided on capacitors C_1, C_2, C_3.

Let q_1, q_2, q_3 be the charges on capacitors C_1, C_2, C_3 respectively.

Then $\quad Q = q_1 + q_2 + q_3 \qquad ...(i)$

and $\quad q_1 = C_1 V, q_2 = C_2 V, q_3 = C_3 V$

Substituting these values in (*i*), we get

$$Q = C_1 V + C_2 V + C_3 V \quad or \quad Q = (C_1 + C_2 + C_3)V \qquad ...(ii)$$

If, in place of all the three capacitors, only one capacitor of capacitance C be connected between A and B; such that on giving it charge Q, the potential difference between its plates be V, then it will be called **equivalent capacitor.** If C be the capacitance of equivalent capacitor, then

$$Q = CV \qquad ...(iii)$$

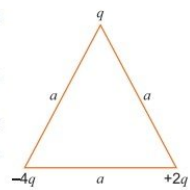
Comparing equations (*ii*) and (*iii*), we get

$CV=(C_1+C_2+C_3)V$ or $\qquad \boldsymbol{C=(C_1+C_2+C_3)}$

Important Note: It may be noted carefully that the formula for the total capacitance in series and parallel combination of capacitors is the reverse of corresponding formula for combination of resistors in current electricity.

Q. 5. (*a*) **Explain why, for any charge configuration, the equipotential surface through a point is normal to the electric field at that point.**
Draw a sketch of equipotential surfaces due to a single charge ($-q$), depicting the electric field lines due to the charge.

(*b*) **Obtain an expression for the work done to dissociate the system of three charges placed at the vertices of an equilateral triangle of side '*a*' as shown below.** [*CBSE North 2016*]



Ans. (*a*) The work done in moving a charge from one point to another on an equipotential surface is zero. If the field is not normal to an equipotential surface, it would have a non zero component along the surface. This would imply that work would have to be done to move a charge on the surface which is contradictory to the definition of equipotential surface.

Mathematically

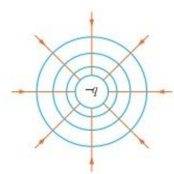
Work done to move a charge dq on a surface can be expressed as

$$dW = dq(\vec{E}.\vec{dr})$$

But $dW = 0$ on an equipotential surface

$\therefore \quad \vec{E} \perp \vec{dr}$

Equipotential surfaces for a charge $-q$ is shown alongside.



(*b*) Work done to dissociate the system = – Potential energy of the system

$$= \frac{-1}{4\pi\varepsilon_0}\left[\frac{(-4q)(q)}{a} + \frac{(2q)(q)}{a} + \frac{(-4q)(2q)}{a}\right]$$

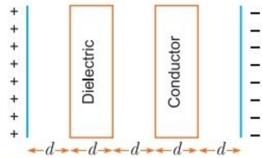
$$= -\frac{1}{4\pi\varepsilon_0}\left[-4q^2 + 2q^2 - 8q^2\right] = +\left[\frac{\mathbf{10q^2}}{\mathbf{4\pi\varepsilon_0 a}}\right]$$

Q. 6. (*i*) **Compare the individual dipole moment and the specimen dipole moment for H_2O molecule and O_2 molecule when placed in**

(*a*) **Absence of external electric field**

(*b*) **Presence of external eclectic field. Justify your answer.**

(*ii*) **Given two parallel conducting plates of area A and charge densities $+\sigma$ and $-\sigma$. A dielectric slab of constant K and a conducting slab of thickness d each are inserted in between them as shown.**



(*a*) **Find the potential difference between the plates.**

(*b*) **Plot E versus x graph, taking $x = 0$ at positive plate and $x = 5d$ at negative plate.**

[CBSE Sample Paper 2016]

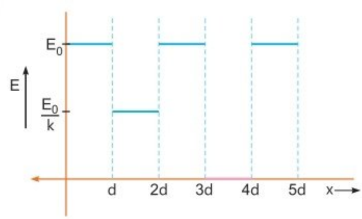
Ans. (*i*)

	Non-Polar (O_2)	Polar (H_2O)
(a) Absence of electric field		
Individual	No dipole moment exists	Dipole moment exists
Specimen	No dipole moment exists	Dipole are randomly oriented. Net P = 0
(b) Presence of electric field		
Individual	Dipole moment exists (molecules become polarised)	Torque acts on the molecules to align them parallel to $\vec{E}$
Specimen	Dipole moment exists	Net dipole moment exists parallel to $\vec{E}$

(*ii*) (*a*) The potential difference between the plates is given by

$$V = E_0 d + \frac{E_0}{K} d + E_0 d + 0 + E_0 d \quad \Rightarrow \quad V = 3E_0 d + \frac{E_0}{K} d$$

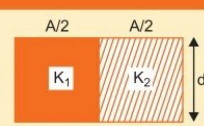
(*b*) E versus x graph



Questions for Practice

1. Choose and write the correct option in the following questions.

(*i*) A parallel plate condenser is filled with two dielectrics as shown. Area of each plate is A metre^2 and the separation is d metre. The dielectric constants are K_1 and K_2 respectively. Its capacitance in farad will be



(*a*) $\frac{\varepsilon_0 A}{d}(K_1 + K_2)$ (*b*) $\frac{\varepsilon_0 A}{d} \cdot \frac{K_1 + K_2}{2}$ (*c*) $\frac{\varepsilon_0 A}{d} 2(K_1 - K_2)$ (*d*) $\frac{\varepsilon_0 A}{d}\left(\frac{K_1 - K_2}{2}\right)$

(*ii*) A parallel plate capacitor is charged to V volt by a battery. The battery is disconnected and the separation between the plates is halved. The new potential difference across the capacitor will be ***[CBSE 2020 (55/3/2)]***

(*a*) $\frac{V}{2}$ (*b*) V (*c*) $2V$ (*d*) $\frac{V}{4}$

(*iii*) The electric potential V at any point (x, y, z) is given by $V = 3x^2$ where x is in metres and V in volts. The electric field at the point (1 m, 0, 2 m) is [*CBSE 2022 (55/2/4), Term-1*]

(*a*) 6 V/m along – x-axis
(*b*) 6 V/m along + x-axis
(*c*) 1.5 V/m along – x-axis
(*d*) 1.5 V/m along + x-axis

(*iv*) An electric dipole of moment p is placed parallel to the uniform electric field. The amount of work done in rotating the dipole by 90° is [*CBSE Sample Paper-2022, Term-1)*]

(*a*) $2pE$ (*b*) pE (*c*) $pE/2$ (*d*) zero

(*v*) Equipotential surface associated with an electric field, which is increasing in magnitude along the X-direction, are

(*a*) planes parallel to YZ-plane.
(*b*) planes parallel to XZ-plane.
(*c*) planes parallel to XY-plane.
(*d*) coaxial cylinder of increasing radii around the X-axis.

(*vi*) Two identical metal plates, separated by a distance d form a parallel-plate capacitor. A metal sheet of thickness $d/2$ is inserted between the plates. The ratio of the capacitance after the insertion of the sheet to that before insertion is

(*a*) $\sqrt{2}:1$ (*b*) 2 : 1 (*c*) 1 : 1 (*d*) 1 : 2

(*vii*) A particle A has charge $+q$ and particle B has charge $+4q$ with each of them having the same mass m. When allowed to fall from rest through same electrical potential difference, the ratio of their speeds $v_A : v_B$ will become

(*a*) 2 : 1 (*b*) 1 : 2 (*c*) 1 : 4 (*d*) 4 : 1

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

(*a*) ***Both A and R are true and R is the correct explanation of A.***
(*b*) ***Both A and R are true but R is not the correct explanation of A.***
(*c*) ***A is true but R is false.***
(*d*) ***A is false and R is also false.***

Assertion (*A*) : The capacitance of a parallel plate capacitor increases when a dielectric constant of medium between the plates.

Reason (*R*) : Capacitance of a parallel plate capacitor is directly proportional to dielectric constant of medium between the plates.

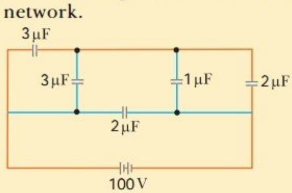
3. What is the electrostatic potential due to an electric dipole at an equatorial point?

4. A hollow metal sphere of radius 10 cm is charged such that the potential on its surface is 5V. What is the potential at the centre of the sphere?

5. Why is the electrostatic potential inside a charged conducting shell constant throughout the volume of the conductor?

6. Find the ratio of the potential differences that must be applied across the parallel and series combination of two capacitors C_1 and C_2 with their capacitances in the ratio 1 : 2 so that the energy stored in the two cases becomes the same. [*CBSE Central 2016*]

7. The figure shows a network of five capacitors connected to a 100 V supply. Calculate the total energy stored in the network.



8. Two capacitors are connected in series. Derive an expression of the equivalent capacitance of the combination. *[CBSE 2023 (55/3/1)]*

9. Two point charges $+q$ and $-q$ are located at points $(3a, 0)$ and $(0, 4a)$ respectively in x-y plane. A third charge Q is kept at the origin. Find the value of Q, in terms of q and a, so that the electrostatic potential energy of the system is zero. *[CBSE 2023 (55/3/1)]*

10. Find the energy lost when the charged capacitor is disconnected from the source and connected in parallel with the uncharged capacitor. Where does this loss of energy appear? *[CBSE Sample Paper 2017]*

11. Two charges 5×10^{-8} C and -3×10^{-8} C are located 16 cm apart. At what point(s) on the line joining the two charges is the electric potential zero? Take the potential at infinity to be zero. *[NCERT]*

12. A regular hexagon of side 10 cm has a charge 5 μC at each of its vertices. Calculate the potential at the centre of the hexagon. *[NCERT]*

13. Three capacitors each of capacitance 9 pF are connected in series:
    (*a*) What is the total capacitance of the combination?
    (*b*) What is the potential difference across each capacitor if the combination is connected to 120 V supply? *[NCERT]*

14. Three capacitors of capacitances 2 pF, 3 pF and 4 pF are connected in parallel.
    (*a*) What is the total capacitance of the combination?
    (*b*) Determine the charge on each capacitor if the combination is connected to a 100 V supply. *[NCERT]*

15. Why do the equipotential surfaces due to a uniform electric field not intersect each other? *[CBSE (F) 2012]*

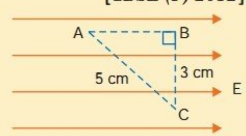
16. "For any charge configuration, equipotential surface through a point is normal to the electric field." Justify. *[CBSE Delhi 2014]*

17. Why is the potential inside a hollow spherical charged conductor constant and has the same value as on its surface? *[CBSE (F) 2012]*

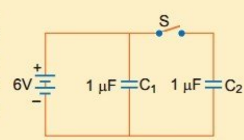
18. A hollow metal sphere of radius 5 cm is charged such that the potential on its surface is 10 V. What is the potential at the centre of the sphere? *[CBSE (AI) 2011]*

19. Why is there no work done in moving a charge from one point to another on an equipotential surface? *[CBSE (F) 2012]*

20. Three points A, B and C lie in a uniform electric field (E) of 5×10^3 NC^{-1} as shown in the figure. Find the potential difference between A and C. *[CBSE (F) 2009]*



21. Figure shows two identical capacitors, C_1 and C_2, each of 1 μF capacitance connected to a battery of 6 V. Initially switch '*S*' is closed. After sometimes '*S*' is left open and dielectric slabs of dielectric constant $K = 3$ are inserted to fill completely the space between the plates of the two capacitors. How will the (*i*) charge and (*ii*) potential difference between the plates of the capacitors be affected after the slabs are inserted? *[CBSE Delhi 2011]*



22. A parallel plate capacitor is charged by a battery, which is then disconnected. A dielectric slab is then inserted in the space between the plates. Explain what changes, if any, occur in the values of
    (*i*) capacitance
    (*ii*) potential difference between the plates
    (*iii*) electric field between the plates, and
    (*iv*) the energy stored in the capacitor. *[CBSE Delhi 2010, (AI) 2009, 2012]*

23. A parallel plate is charged by a battery. When the battery remains connected, a dielectric slab is inserted in the space between the plates. Explain what changes if any, occur in the values of

(*i*) potential difference between the plates (*ii*) electric field strength between the plates

(*iii*) capacitance (*iv*) charge on the plates

(*v*) energy stored in the capacitor. [*CBSE Delhi 2010*]

24. A parallel plate capacitor of capacitance C is charged to a potential V. It is then connected to another uncharged capacitor having the same capacitance. Find out the ratio of the energy stored in the combined system to that stored initially in the single capacitor. [*CBSE (AI) 2014*]

25. Two capacitors of unknown capacitances C_1 and C_2 are connected first in series and then in parallel across a battery of 100 V. If the energy stored in the two combinations is 0.045 J and 0.25 J respectively, determine the value of C_1 and C_2. Also calculate the charge on each capacitor in parallel combination. [*CBSE Delhi 2015*]

26. A 12 pF capacitor is connected to a 50 V battery. How much electrostatic energy is stored in the capacitor? If another capacitor of 6 pF is connected in series with it with the same battery connected across the combination, find the charge stored and potential difference across each capacitor. [*CBSE Delhi 2017*]

27. Two identical capacitors of 12 pF each are connected in series across a battery of 50 V. How much electrostatic energy is stored in the combination? If these were connected in parallel across the same battery, how much energy will be stored in the combination now?

Also find the charge drawn from the battery in each case. [*CBSE Delhi 2017*]

28. A slab of material of dielectric constant K has the same area as that of the plates of a parallel plate capacitor but has the thickness $d/2$, where d is the separation between the plates. Find out the expression for its capacitance when the slab is inserted between the plates of the capacitor.

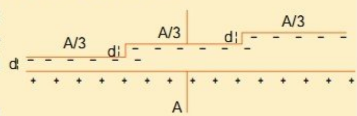
[*HOTS*] [*CBSE (AI) 2013*]

29. (*a*) Deduce the expression for the potential energy of a system of two charges q_1 and q_2 located at $\vec{r}_1$ and $\vec{r}_2$ respectively in an external electric field.

(*b*) Three point charges, $+Q$, $+2Q$ and $-3Q$ are placed at the vertices of an equilateral triangle ABC of side l. If these charges are displaced to the mid-points A_1, B_1 and C_1 respectively, find the amount of the work done in shifting the charges to the new locations.

30. A capacitor is made of a flat plate of area A and second plate having a stair like structure as shown in figure below. If width of each stair is $A/3$ and height is d. Find the capacitance of the arrangement.

[*CBSE Sample Paper 2017*]



Answers

1. (*i*) (*b*) (*ii*) (*a*) (*iii*) (*a*) (*iv*) (*b*) (*v*) (*a*) (*vi*) (*b*) (*vii*) (*b*)

2. (*a*) 6. $3:\sqrt{2}$ 7. 0.02J 9. $\frac{12q}{5}$C 11. 10 cm 12. 2.7×10^6 V

13. (*a*) 3 PF (*b*) 40V 14. (*a*) 9pF (*b*) 2×10^{-10}C, 3×10^{-10}C, 4×10^{-10}C

18. 10V 20. 200V 21. (*i*) 18μC (*ii*) 2V 24. 1:2

25. 38.2 mF, 11.8 mF, 38.2×10^{-4} C, 11.8×10^{-4} C

26. 2×10^{-4} C, 2×10^{-4} C and $\frac{50}{3}$ V, $\frac{100}{3}$ V

27. 75×10^{-10}J, 3×10^{-8}J, 3×10^{10}C , 1.2×10^{-9} C.

29. (*b*) $\frac{-7KQ^2}{l}$J 30. $\frac{11A\varepsilon_0}{18d}$

3 Current Electricity

POINTS TO REMEMBER

The study of electric charges in motion is called current electricity.

1. Electric Current

The rate of flow of electric charges through a conductor is called electric current.

Current is defined as the rate of flow of electric charge.

$$I = \frac{q}{t}$$

or Instantaneous current, $I = \frac{dq}{dt}$

Conventionally, the direction of current is taken along the direction of flow of positive charge and opposite to the direction of flow of negative charge (electron).

Current is a scalar quantity. SI unit of electric current is ampere (A).

2. Flow of Electric Charges in a Metallic Conductor

A metallic conductor contains free electrons as charge carriers, while positive ions are fixed in the lattice. When no potential difference is applied, the motion of free electrons is random so there is no net current in any direction. When a potential difference is applied across the conductor the free electrons drift along the direction of positive potential so a current begins to flow in the conductor, the direction of current is opposite to the direction of the net electron flow.

3. Drift Velocity and Mobility

Drift velocity is defined as the average velocity with which the free electrons get drifted towards the positive end of the conductor under the influence of an external electric field applied. It is given by the relation

$$\vec{v}_d = -\frac{e\vec{E}}{m}\tau$$

where m = mass of electron, e = charge of electron

E = electric field applied

τ = relaxation time $= \dfrac{\text{mean free path}}{\text{root mean square velocity of electrons}}$

Mobility of an ion is defined as the drift velocity per unit electric field *i.e.*,

$$\mu = \frac{v_d}{E} = \frac{e\tau}{m}$$

Its unit is m^2/Vs.

4. Relation between Drift Velocity and Mobility with Electric Current

Current, in terms of drift velocity $I = neAv_d$,

Current, in terms of mobility $I = neA\mu E$,

where, n = number of free electrons per metre^3,

A = cross-sectional area of conductor.

5. Ohm's Law

It states that the current flowing in a conductor is directly proportional to the potential difference applied across the conductor provided physical conditions, *e.g.*, temperature, pressure, etc. remain the same.

$I \propto V$ or $V \propto I$ or $V = RI$

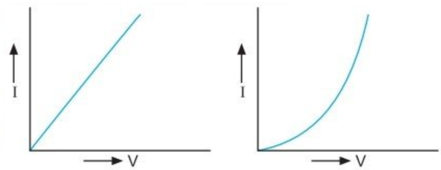
where R is called electrical resistance. Its unit is volt/ampere or ohm.

Ohm's law is not applicable to all types of conductor. It is applicable only for those conducting materials for which V-I graph is linear.

6. V-I Characteristics: Linear and Non-linear — Ohmic and Non-ohmic Conductors

The conductors or circuit elements for which V-I graph is linear are called **ohmic conductors**. The examples are metallic conductors.

On the other hand, the circuit elements for which V-I graph is non-linear are called **non-ohmic conductors.** The examples are junction diodes and transistors.



(i) Ohmic (ii) Non-ohmic

Electrical Energy and Power

7. Joule's Law of Heating

The heat which is produced (or consumed) due to the flow of current in a conductor, is expressed in joules.

Mathematically, amount of heat produced (consumed) is proportional to square of amount of current flowing through conductor, electrical resistance of wire and the time of current flow through it.

So, $\quad H \propto I^2 Rt$

$$\Rightarrow \quad H = \frac{I^2 Rt}{J}$$

where J is a joule constant. 1 joule constant is 4.18×10^3 J/k cal

$$\Rightarrow \quad H = \frac{I^2 Rt}{J} = \frac{VIt}{J} = \frac{V^2}{JR}t$$

Where V is the potential difference across wire.

8. Power

Rate of energy dissipation in a resistor is called the power *i.e.*,

$$\text{Power} \quad P = \frac{W}{t} = VI = I^2 R = \frac{V^2}{R}$$

The unit of power is watt.

9. Resistivity (or Specific Resistance)

Resistivity of a substance is defined as the resistance offered by a wire of that substance of 1 metre length and 1 square metre cross-sectional area.

Resistivity depends only on the material and is independent of dimensions at a given temperature. The SI unit of resistivity is ohm × metre (Ωm).

10. Conductance and Conductivity

The reciprocal of resistance is called the conductance (G)

i.e., $$G = \frac{1}{R}$$

Its SI unit is $(\text{ohm})^{-1}$ or mho or siemen (S).

The reciprocal of resistivity is called the conductivity (σ).

i.e., $$\sigma = \frac{1}{\rho}$$

Its SI unit is ohm^{-1} metre^{-1} (or mho m^{-1}) or Sm^{-1}

11. Temperature Dependence of Resistance

The resistance of a metallic conductor increases with increase of temperature.

$$R_t = R_0\,[1 + \alpha\,(t - t_0)]$$

where R_0 is resistance at 0°C and R_t is resistance at t°C and α is temperature coefficient of resistance. In general if variation of temperature is not too large, then

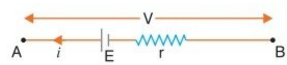
$$\alpha = \frac{R_2 - R_1}{R_1\,(t_2 - t_1)} \text{ per}^{\circ}\text{C or per K}$$

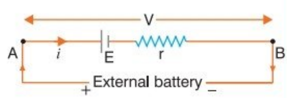
In terms of resistivity

$$\alpha_r = \frac{\rho_2 - \rho_1}{\rho_1\,(t_2 - t_1)} \text{ per }^{\circ}\text{C or per K}$$

However, the resistance of a semiconductor decreases with rise in temperature.

12. Electric Cell





It is a device which converts chemical energy into electrical energy.

EMF of a cell (E) is defined as the maximum potential difference when no current is being drawn from the cell.

Terminal Potential difference (V) is defined as the potential difference when current is being delivered to external load resistance.

Internal Resistance (r) of a cell is the hindrance offered by the electrolyte of cell to the flow of current. Internal resistance of a cell depends on

(*i*) separation between electrodes.

(*ii*) area of immersed part of electrodes.

(*iii*) concentration and nature of electrolyte.

$$E = V + Ir \quad \Rightarrow \quad V = E - Ir$$

When a current I is passed in cell in opposite direction by external battery, then terminal potential difference $V = E + Ir$

13. Combination of Cells

(*i*) When n-identical cells are connected in series

Current, $$I\left(= \frac{E_{net}}{R_{ext} + R_{int}}\right) = \frac{nE}{R + nr}$$

For useful series combination, the condition is $R_{ext} >> R_{int}$

(*ii*) When m-identical cells are connected in parallel

$$I = \frac{E_{net}}{R_{ext} + R_{\text{int}}} = \frac{E}{R + r/m}$$

Condition of useful parallel combination is $R < r/m$.

(*iii*) When $N = mn$, cells are connected in mixed grouping (m-rows in parallel, each row containing n cells in series)

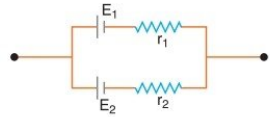
Current, $$I = \frac{nE}{R + \frac{nr}{m}} = \frac{mnE}{mR + nr}$$

Condition for useful mixed grouping is $R_{ext} = R_{int}$

i.e., $$R = \frac{nr}{m}$$

(*iv*) When two cells of different emfs E_1 and E_2 and different internal resistances r_1 and r_2 are connected in parallel as shown in fig. then net emf of combination is

$$E = \frac{\frac{E_1}{r_1} + \frac{E_2}{r_2}}{\frac{1}{r_1} + \frac{1}{r_2}} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$$



Net internal resistance r_{int}

$$\frac{1}{r_{int}} = \frac{1}{r_1} + \frac{1}{r_2} \Rightarrow r_{int} = \frac{r_1 r_2}{r_1 + r_2}$$

14. Kirchhoff's Laws

(*i*) **First law (or junction law):** The algebraic sum of currents meeting at any junction in an electrical network is zero,

i.e., $\Sigma I = 0$

This law is based on conservation of charge.

(*ii*) **Second law (or loop law):** The algebraic sum of potential differences of different circuit elements of a closed circuit (or mesh) is zero, *i.e.*,

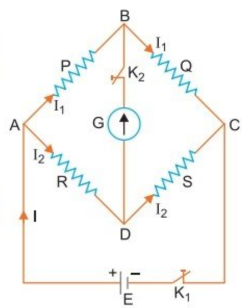
$$\Sigma V = 0$$

This law is based on conservation of energy.

15. Wheatstone's Bridge

It is an arrangement of four resistances *P*, *Q*, *R*, and *S* forming a closed circuit. A potential difference is applied across terminals *A* and *C*. A galvanometer is connected across *B* and *D*. The condition of null point (no deflection in galvanometer) is

$$\frac{P}{Q} = \frac{R}{S}$$



Multiple Choice Questions

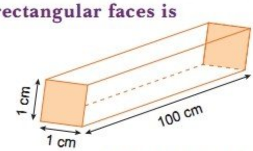
Choose and write the correct option(s) in the following questions.

1. **The resistance of a metal wire increases with increasing temperature on account of** *[CBSE 2020 (55/1/2)]*

   (*a*) decrease in free electron density.
   (*b*) decrease in relaxation time.
   (*c*) increase in mean free path.
   (*d*) increase in the mass of electron.

2. **Dimensions of a block are 1cm × 1cm × 100 cm. If specific resistance of its material is 3×10^{-7} Ω m, then the resistance between the opposite rectangular faces is**

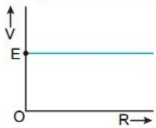
   (*a*) $3 \times 10^{-9}\ \Omega$
   (*b*) $3 \times 10^{-7}\ \Omega$
   (*c*) $3 \times 10^{-5}\ \Omega$
   (*d*) $3 \times 10^{-3}\ \Omega$

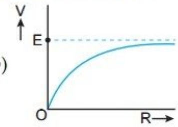


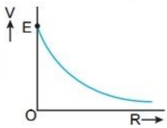
3. **Resistivity of a given conductor depends upon** *[CBSE 2020 (55/2/2)]*

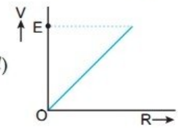
   (*a*) temperature.
   (*b*) length of conductor.
   (*c*) area of cross-section.
   (*d*) shape of the conductor.

4. A cell of emf (E) and internal resistance r is connected across a variable external resistance R. The graph of terminal potential difference V as a function of R is **[*CBSE 2020 (55/4/1)*]**

(*a*) 

(*b*) 

(*c*) 

(*d*) 

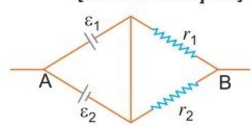
5. In a Wheatstone bridge, all the four arms have equal resistance R. If resistance of the galvanometer arm is also R, then equivalent resistance of the combination is

(*a*) R (*b*) $2R$ (*c*) $\frac{R}{2}$ (*d*) $\frac{R}{4}$

6. Consider a current carrying wire (current I) in the shape of a circle. Note that as the current progresses along the wire, the direction of J (current density) changes in an exact manner, while the current I remain unaffected. The agent that is essentially responsible for is **[*NCERT Exemplar*]**

(*a*) source of emf.
(*b*) electric field produced by charges accumulated on the surface of wire.
(*c*) the charges just behind a given segment of wire which push them just the right way by repulsion.
(*d*) the charges ahead.

7. Two batteries of emf ε_1 and ε_2 ($\varepsilon_2 > \varepsilon_1$) and internal resistances r_1 and r_2 respectively are connected in parallel as shown in Figure. **[*NCERT Exemplar*]**



(*a*) The equivalent emf ε_{eq} of the two cells is between ε_1 and ε_2, *i.e.*, $\varepsilon_1 < \varepsilon_{eq} < \varepsilon_2$
(*b*) The equivalent emf ε_{eq} is smaller than ε_1.
(*c*) The ε_{eq} is given by $\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2$ always.
(*d*) ε_{eq} is independent of internal resistances r_1 and r_2.

8. The drift velocity of the free electrons in a conducting wire carrying a current i is v. If in a wire of the same metal, but of double the radius, the current be $2I$, then the drift velocity of the electrons will be

(*a*) $v/4$ (*b*) $v/2$ (*c*) v (*d*) $4v$

9. The element of a heater is rated (P, V). If it is connected across a source of voltage $V/2$, then the power communed by it will be **[*CBSE 2020 (55/3/1)*]**

(*a*) P (*b*) $2P$
(*c*) $\frac{P}{2}$ (*d*) $\frac{P}{4}$

10. A metal rod of length 10 cm and a rectangular cross-section of 1cm × $\frac{1}{2}$ cm is connected to a battery across opposite faces. The resistance will be **[*NCERT Exemplar*]**

(*a*) maximum when the battery is connected across 1 cm × $\frac{1}{2}$ cm faces.
(*b*) maximum when the battery is connected across 10 cm × 1 cm faces.
(*c*) maximum when the battery is connected across 10 cm × $\frac{1}{2}$ cm faces.
(*d*) same irrespective of the three faces.

11. Which of the following characteristics of electrons determines the current in a conductor? [*NCERT Exemplar*]

(*a*) Drift velocity alone
(*b*) Thermal velocity alone
(*c*) Both drift velocity and thermal velocity
(*d*) Neither drift nor thermal velocity.

12. Temperature dependence of resistivity ρ(T) of semiconductors insulators and metals is significantly based on the following factors. [*NCERT Exemplar*]

(*a*) Number of charge carriers can change with temperature T.
(*b*) Time interval between two successive collision can depend on T.
(*c*) Length of material can be a function of T.
(*d*) Mass of carriers is a function of T.

13. A cell of internal resistance r is connected across an external resistance R can supply maximum current when [*CBSE 2020 (55/2/1)*]

(*a*) $R = r$ (*b*) $R > r$ (*c*) $R = \frac{r}{2}$ (*d*) $R = 0$

14. Kirchhoff's junction rule is a reflection of [*NCERT Exemplar*]

(*a*) conservation of current density vector.
(*b*) conservation of charge.
(*c*) the fact that the momentum with which a charged particle approaches a junction is unchanged (as a vector) as the charged particle leaves the junction.
(*d*) the fact that there is no accumulation of charged at a junction.

15. The ratio of current density and electric field is called [*CBSE 2020 (55/2/2)*]

(*a*) Resistivity (*b*) Conductivity
(*c*) Drift velocity (*d*) Mobility

16. The electrical resistance of a conductor [*CBSE 2020 (55/3/1)*]

(*a*) varies directly proportional to its area of cross-section.
(*b*) decreases with increase in its temperature.
(*c*) decreases with increase in its conductivity.
(*d*) independent or its shape but depends only on its volume.

17. For a fixed potential difference applied across a conductor, the drift speed of free electrons does not depend upon [*CBSE 2020 (55/2/3)*]

(*a*) free electron density in the conductor.
(*b*) mass of the electrons.
(*c*) length of the conductor
(*d*) temperature of the conductor.

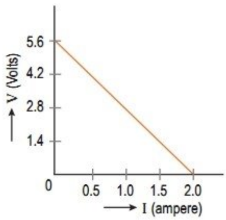
18. Two sources of equal emf are connected in series. This combination is, in turn connected to an external resistance R. The internal resistance of two sources are r_1 and r_2 ($r_2 > r_1$). If the potential difference across the source of internal resistance r_2 is zero, then R equals to [*CBSE 2022 (55/2/4), Term-1*]

(*a*) $\frac{r_1 + r_2}{r_2 - r_1}$ (*b*) $r_2 - r_1$
(*c*) $\frac{r_1 r_2}{r_2 - r_1}$ (*d*) $\frac{r_1 + r_2}{r_1 r_2}$

19. If n, e, τ and m have their usual meanings, then the resistance of a wire of length l and cross-sectional area A is given by [*CBSE 2022 (55/2/4), Term-1*]

(*a*) $\frac{ne^2 A}{2m\tau l}$ (*b*) $\frac{ml}{ne^2 \tau A}$
(*c*) $\frac{m\tau A}{ne^2 l}$ (*d*) $\frac{ne^2 \tau A}{2ml}$

20. A straight line plot showing the terminal potential difference (V) of a cell as a function of current (I) drawn from it, is shown in the figure. The internal resistance of the cell would be then *[CBSE Sample Paper-2022), Term-1]*



(*a*) 2.8 ohms (*b*) 1.4 ohms (*c*) 1.2 ohms (*d*) zero

21. A car battery is charged by a 12 V supply, and energy stored in it is 7.20×10^5 J. The charge passed through the battery is *[CBSE 2022 (55/2/4), Term-1]*

(*a*) 6.0×10^4 C (*b*) 5.8×10^3 J (*c*) 8.64×10^6 J (*d*) 1.6×10^5 C

22. We use alloys for making standard resistors because they have *[CBSE Sample Paper-2022, Term-1]*

(*a*) low temperature coefficient of resistivity and high specific resistance
(*b*) high temperature coefficient of resistivity and low specific resistance
(*c*) low temperature coefficient of resistivity and low specific resistance
(*d*) high temperature coefficient of resistivity and high specific resistance

23. A constant voltage is applied between the two ends of a uniform metallic wire, heat 'H' is developed in it. If another wire of the same material, double the radius and twice the length as compared to original wire is used then the heat developed in it will be *[CBSE Sample Paper-2022, Term-1]*

(*a*) $H/2$ (*b*) H (*c*) $2H$ (*d*) $4H$

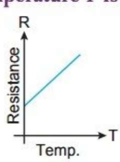
24. If the potential difference V applied across a conductor is increased to $2V$ with its temperature kept constant, free electrons in a conductor *[CBSE Sample Paper-2022, Term-1]*

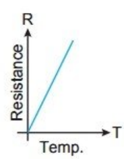
(*a*) remain the same (*b*) become half of its previous value
(*c*) be double of its initial value (*d*) become zero

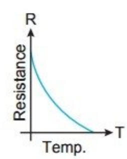
25. A battery is connected to the conductor of non-uniform cross section area. The quantities or quantity which remains constant is *[CBSE Sample Paper-2022, Term-1]*

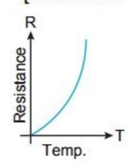
(*a*) electric field only (*b*) drift speed and electric field
(*c*) electric field and current (*d*) current only

26. For a metallic conductor, the correct representation of variation of resistance R with temperature T is *[CBSE 2023 (55/1/1)]*

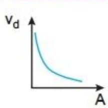
(*a*)


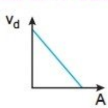
(*b*)


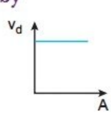
(*c*)


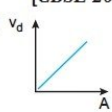
(*d*)


27. A steady current flows through a metallic wire whose area of cross-section (A) increases continuously from one end of the wire to the other. The magnitude of drift velocity (v_d) of the free electrons as a function of 'A' can be shown by *[CBSE 2023 (55/1/1)]*

(*a*)


(*b*)


(*c*)


(*d*)


28. A current of 0.8 A flows in a conductor of 40 Ω for 1 minute. The heat produced in the conductor will be [*CBSE 2023 (55/2/1)*]

(*a*) 1445 J (*b*) 1536 J (*c*) 1569 J (*d*) 1640 J

29. A cell of emf E is connected across an external resistance R. When current 'I' is drawn from the cell, the potential difference across the electrodes of the cell drops to V. The internal resistance 'r' of the cell is [*CBSE 2023 (55/2/1)*]

(*a*) $\left(\frac{E-V}{E}\right)R$ (*b*) $\left(\frac{E-V}{R}\right)$ (*c*) $\frac{(E-V)R}{I}$ (*d*) $\left(\frac{E-V}{V}\right)R$

30. The current density due to drift of electrons in a conductor is given by (symbols have their usual meanings) [*CBSE 2023 (55/3/1)*]

(*a*) $n\,e\,A\,v_d$ (*b*) $\frac{n\,A\,v_d}{e}$ (*c*) $\frac{n\,v_d}{e\,A}$ (*d*) $n\,e\,v_d$

Answers

1. (*b*)	**2.** (*b*)	**3.** (*a*)	**4.** (*b*)	**5.** (*a*)	**6.** (*b*)	**7.** (*a*)
8. (*b*)	**9.** (*d*)	**10.** (*a*)	**11.** (*a*)	**12.** (*a*), (*b*)	**13.** (*a*)	**14.** (*b*), (*d*)
15. (*b*)	**16.** (*c*)	**17.** (*a*)	**18.** (*b*)	**19.** (*b*)	**20.** (*a*)	**21.** (*a*)
22. (*a*)	**23.** (*c*)	**24.** (*c*)	**25.** (*d*)	**26.** (*a*)	**27.** (*a*)	**28.** (*b*)
29. (*d*)	**30.** (*d*)					

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(*a*) ***Both A and R are true and R is the correct explanation of A.***

(*b*) ***Both A and R are true but R is not the correct explanation of A.***

(*c*) ***A is true but R is false.***

(*d*) ***A is false and R is also false.***

1. Assertion (*A*) : An electron has a high potential energy when it is at a location associated with a more negative value of potential, and a low potential energy when at a location associated with a more positive potential. [*CBSE Sample Paper-2022, Term-1*]

Reason (*R*) : Electrons move from a region of higher potential to region of lower potential.

2. Assertion (*A*) : The current density is a vector quantity.

Reason (*R*) : Current density has magnitude current per unit area and is directed along the direction of current.

3. Assertion (*A*) : The connecting wires are made of copper.

Reason (*R*) : Copper has very high electrical conductivity.

4. Assertion (*A*) : Material used in construction of a standard resistance is constantan.

Reason (*R*) : The temperature coefficient of resistance of constantan is negligible.

5. Assertion (*A*) : An electrical bulb starts glowing instantly as it is switched on.

Reason (*R*) : Drift speed of electrons in a metallic wire is very large. [*AIIMS 2017*]

6. Assertion (*A*) : With increase in drift velocity, the current flowing through a metallic conductor decreases.

Reason (*R*) : The current flowing in a conductor is inversely proportional to drift velocity.

7. **Assertion (*A*)** : The current flows in a conductor when there is an electric field within the conductor.

Reason (*R*) : The electrons in a conductor drift only in the presence of electric field.

8. **Assertion (*A*)** : The conductivity of an electrolyte is very low as compared to a metal at room temperature.

Reason (*R*) : The number density of free ions in electrolyte is much smaller as compared to number density of free electrons in metals. Further, ions drift much more slowly, being heavier. **[*AIIMS 2015*]**

9. **Assertion (*A*)** : The internal resistance of a cell is constant.

Reason (*R*) : Ionic concentration of the electrolyte remains same during use of a cell. **[*CBSE 2023 (55/3/1)*]**

10. **Assertion (*A*)** : When three electric bulbs of power 200 W, 100 W and 50 W are connected in series to a source, the power consumed by the 50 W bulb is maximum.

Reason (*R*) : In a series circuit, current is the same through each bulb, but the potential difference across each bulb is different. **[*CBSE 2023 (55/4/1)*]**

Answers

1. (*c*) **2.** (*a*) **3.** (*a*) **4.** (*a*) **5.** (*c*) **6.** (*d*) **7.** (*a*)
8. (*a*) **9.** (*d*) **10.** (*b*).

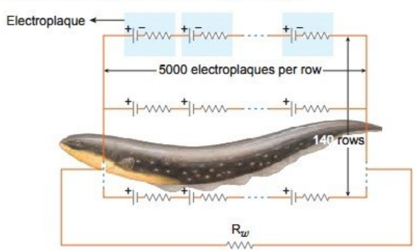
COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Case-based/Passage-based Questions

Read the paragraph given below and answer the questions that follow:

1. **Eel: The Electric Fish**

Electric fish are able to generate current with biological cells called electroplaques, which are physiological emf devices. The electro-plaques in the South American ell shown in the photograph that opens this chapter are arranged in 140 rows, each row stretching horizontally along the body and each containing 5000 electro-plaques. The arrangement is suggested in figure each electro-plaque has an emf (ε) of 0.15V and an internal resistance (*r*) of 0.25Ω. The water surrounding the eel completes a circuit between the two ends of the electroplaque array, one end at the animal's head and the other near its tail.



(*i*) **If the water surrounding the eel has resistance $R_w = 800\ \Omega$ how much current can the eel produce in the water?**

(*a*) 6.6 mA (*b*) 6.6 A
(*c*) 0.93 A (*d*) 9.3 mA

(*ii*) **If the cell has on emf of 4 V and the internal resistance of this cell is 0.2 Ω, it is connected to resistance of 3.8 Ω, terminal voltage through the cell will be**

(*a*) 3.8 V (*b*) 4 V (*c*) 0.2 V (*d*) 1.8 V

(*iii*) **For a cell, the terminal potential difference is 3.6 V, when the circuit is open. If the potential difference reduces to 3 V, when cell is connected to a resistance of 5 Ω, the internal resistance of cell is**

(*a*) 1 Ω (*b*) 2 Ω (*c*) 4 Ω (*d*) 8 Ω

(*iv*) **A group of girls connected 10 identical cell first in series and then in parallel across a bulb of resistance 50 Ω and they see that the reading of the ammeter 1 A in both cases. Then the internal resistance of any one cell will be**

(*a*) 100 Ω (*b*) 50 Ω (*c*) 10 Ω (*d*) 5 Ω

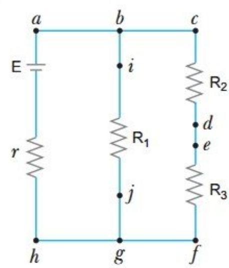
OR

If *n* identical cells emf and internal resistance *r* are connected parallel then the equivalent emf of the combination will

(*a*) $\frac{Er}{n}$ (*b*) $\frac{E}{n}$ (*c*) E (*d*) $\frac{nE}{r}$

2. An experiment was set up with the circuit diagram shown in figure.

Given that $R_1 = 10\,\Omega, R_2 = R_3 = 5\,\Omega, r = 0\,\Omega$ and $E = 5\text{V}$ **[*CBSE 2022 (55/2/4), Term-1, Modified*]**



(*i*) **The points with the same potential are**

(*a*) b, c, d (*b*) f, h, j (*c*) d, e, f (*d*) a, b, j

(*ii*) **The current through branch *bg* is**

(*a*) 1 A (*b*) $\frac{1}{3}$ A (*c*) $\frac{1}{2}$ A (*d*) $\frac{2}{3}$ A

(*iii*) **The power dissipated in R_1 is**

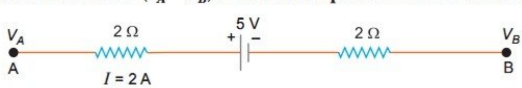
(*a*) 2 W (*b*) 2.5 W (*c*) 3 W (*d*) 4.5 W

(*iv*) **The potential difference across R_3 is**

(*a*) 1.5 V (*b*) 2 V (*c*) 2.5 V (*d*) 3 V

OR

The potential difference ($V_A - V_B$) between the points *A* and *B* in the given figure is



(*a*) – 3 V (*b*) +3 V (*c*) –13 V (*d*) +13 V

Explanations

1. (*i*) (*c*) The total emf, E_{row} along a row of 5000 electro-plaque

$$E_{\text{row}} = 5000\,E = 5000 \times 0.15 = 750 \text{ V}$$

Now, Total internal resistance in row,

$$r_{\text{row}} = (5000)r = (5000 \times 0.25) = 1250\ \Omega.$$

The equivalent resistance of this combination,

$$r_{\text{eq}} = \frac{r_{\text{row}}}{140} = \frac{1250}{140} = 8.93\ \Omega,\quad E_{\text{net}} = E_{\text{row}}$$

Hence, I produce by eel in water, $R_w = 800\ \Omega$

$$\therefore \qquad I = \frac{E_{net}}{R + r_{eq}} = \frac{750}{800 + 8.93} = 0.927\text{A} \simeq 0.93 \text{ A}$$

[**Note:** In parallel combination of cell having equal internal resistance, $E_{\text{net}} = E$]

(*ii*) (*a*) Here, $I = \dfrac{E}{R+r} = \dfrac{4}{3.8+0.2} = \dfrac{4}{4} = 1 \text{ A}$

Now, $V = E - Ir = 4 - 1 \times 0.2 = 3.8 \text{ V}$

(*iii*) (*a*) Given, $E = 3.6 \text{ V}, V = 3\text{V}, R = 5\ \Omega$

then, $I = \dfrac{V}{R} = \dfrac{3}{5}\text{A}.$

Now, $E = V + IR$

$$\therefore \qquad r = \frac{E - V}{I} = \frac{3.6 - 3}{\frac{3}{5}} = \frac{0.6 \times 5}{3} = 1\ \Omega$$

(*iv*) (*b*) **Case I:** When cells connected in series, $E_{\text{net}} = 10\,E$

$$I = \frac{E_{\text{net}}}{R + 10r} = \frac{10E}{50 + 10\,r} \qquad \text{...}(i)$$

Case II: When cell connected in parallal, $E_{\text{net}} = E$

$$I = \frac{E_{\text{net}}}{R + \frac{r}{10}} = \frac{E}{50 + \frac{r}{10}} \qquad \text{...}(ii)$$

Now, in both case ammeter reading is same,

$$I_s = I_p$$

$$\Rightarrow \qquad \frac{10E}{50 + 10r} = \frac{E}{50 + \frac{r}{10}}$$

$$\Rightarrow \qquad 500 + \frac{10r}{10} = 50 + 10r \qquad \Rightarrow \quad 9r = 450 \qquad \therefore\ r = \frac{450}{9} = 50\ \Omega$$

OR

(*c*) In parallel combination of cell,

$$E_{\text{eq}} = \frac{\frac{E_1}{r_1} + \frac{E_2}{r_2} + \dots \frac{E_n}{r_n}}{\frac{1}{r_1} + \frac{1}{r_2} + \dots \frac{1}{r_n}} = \frac{\frac{nE}{r}}{\frac{n}{r}} = E$$

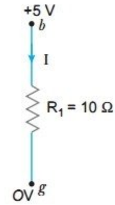
2. (*i*) (*b*) Here, $r = 0$, so no potential drop across r.

$\therefore \qquad$ P.d of cell $= V_a - V_b = (5 - 0) = 5\text{V}$

Now, $V_a = 5\text{V}, V_h = 0\text{V}$

From the circuit, common points a, b, i, c have same potential and common points h, g, j, f have same potential.

(*ii*) (*c*) Potential difference across bg,



$$V_{bg} = +5 - 0 = 5 \text{ V}$$

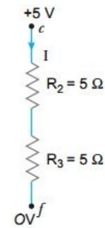
Current through branch bg,

$$\therefore \quad I = \frac{V_{bg}}{R_1} = \frac{5}{10} = \frac{1}{2}\text{A}$$

(*iii*) (*b*) Power dissipated in R_1,

$$P \quad = \frac{V^2}{R} = \frac{(5)^2}{10} = \frac{25}{10} = 2.5 \text{ W}$$

(*iv*) (*c*) Potential difference across cf branch,



$$V_{cf} = (5 - 0) = 5\text{V}$$

$$R_{eq} = R_2 + R_3 = (5 + 5) = 10\ \Omega$$

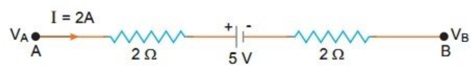
$$\therefore \quad I = \frac{V_{cf}}{R_{eq}} = \frac{5}{10} = \frac{1}{2}\text{A}$$

Then, potential difference across R_3,

$$\therefore \quad V = IR_3 = \frac{1}{2} \times 5 = 2.5 \text{ V}$$

OR

(*d*) From *KVL*,



$$V_{AB} = V_A - V_B = 2 \times 2 + 5 + 2 \times 2$$

$$= 4 + 5 + 4 = 13 \text{ V}$$

CONCEPTUAL QUESTIONS

Q. 1. When a potential difference is applied across the ends of a conductor, how is the drift velocity of the electrons related to the relaxation time. **[*CBSE 2019 (55/1/2)*]**

Ans. 4 Drift velocity of electrons, v_d is given by,

$$\boxed{\vec{v}_d = -\frac{e\vec{E}}{m}\tau}$$

where, $\vec{E}$ is the external electric field and 'τ' is the relaxation time.

Hence, we can see that magnitude of drift velocity of electron varies linearly with relaxation time for a constant potential difference (and also electric field).

Thus, drift velocity of electrons is related directly to the relaxation time.

[*Topper's Answer 2019*]

Q. 2. Define the term 'Mobility' of electrons. Give its SI unit. [*CBSE 2023 (55/4/1)*]

Ans. Mobility is defined as the magnitude of the drift velocity acquired by it in a unit electric field. The SI unit of mobility is m^2/Vs or $m^2\,V^{-1}s^{-1}$.

Q. 3. How does the mobility of electrons in a conductor change, if the potential difference applied across the conductor is doubled, keeping the length and temperature of the conductor constant? [*CBSE 2019 (55/1/1)*]

Ans. Mobility is defined as the magnitude of drift velocity per unit electric field.

$$\mu = \frac{|v_d|}{E} = \frac{eE}{m.E}\tau = \frac{e}{m}\tau$$

At constant temperature and length, there is no change in relaxation time *i.e.*, $\tau \propto \frac{1}{T}$. Also it does not depend on potential difference.

Hence, on changing the potential difference, there is no change in mobility of electrons.

Q. 4. Define electrical conductivity of a conductor and give its SI unit. On what factors does it depend? [*CBSE Delhi 2014, (East) 2016, CBSE 2023 (55/4/1)*]

Ans. The conductivity of a material equals the reciprocal of the resistance of its wire of unit length and unit area of cross-section.

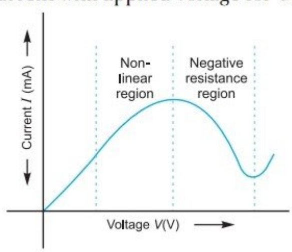
Its SI unit is

$$\left(\frac{1}{\text{ohm - metre}}\right) \text{ or ohm}^{-1}\text{ m}^{-1} \text{ or (mho m}^{-1}) \text{ or siemen m}^{-1}$$

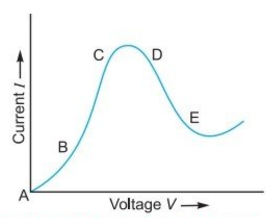
It depends upon number density, nature of material, relaxation time and temperature.

Q. 5. Plot a graph showing variation of current versus voltage for the material GaAs. [*CBSE Delhi 2014*]

Ans. The variation of electric current with applied voltage for GaAs is as shown.



Q. 6. Graph showing the variation of current versus voltage for a material GaAs is shown in the figure. Identify the region of

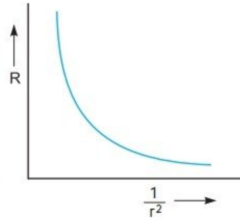


(*i*) negative resistance (*ii*) where Ohm's law is obeyed. [*CBSE Delhi 2015*]

Ans. (*i*) In region *DE*, material GaAs (Gallium Arsenide) offers negative resistance, because slope $\frac{\Delta V}{\Delta I} < 0$.

(*ii*) The region *BC* approximately passes through the origin, (or current also increases with the increase of voltage). Hence, it follows Ohm's law and in this region $\frac{\Delta V}{\Delta I} > 0$.

Q. 7. Plot a graph showing the variation of resistance of a conducting wire as a function of its radius, keeping the length of the wire and its temperature as constant. *[CBSE (F) 2013]*



Ans. Resistance of a conductor of length l, and radius r is given by

$$R = \rho \frac{l}{\pi r^2}; \qquad \text{thus} \qquad R \propto \frac{1}{r^2}$$

Q. 8. The emf of a cell is always greater than its terminal voltage. Why? Give reason. *[CBSE Delhi 2013]*

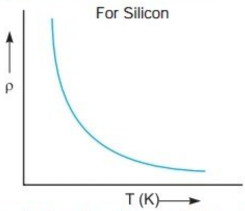
Ans. (*i*) In an open circuit, the emf of a cell and terminal voltage are same.

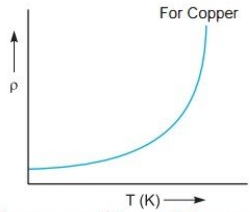
(*ii*) In closed circuit, a current is drawn from the source, so, $V = E - Ir$, it is true/valid, because each cell has some finite internal resistance.

Q. 9. Two materials Si and Cu, are cooled from 300 K to 60 K. What will be the effect on their resistivity? *[CBSE (F) 2013]*

Ans. In silicon, the resistivity increases.

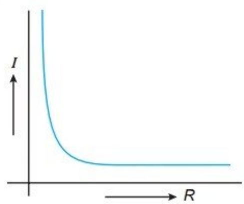
In copper, the resistivity decreases.





Q. 10. Plot a graph showing the variation of current '*I*' versus resistance '*R*', connected to a cell of emf *E* and internal resistance '*r*'.

Ans. $I = \frac{E}{r + R}$



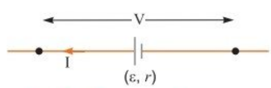
Q. 11. Give an example of a material each for which temperature coefficient of resistivity is (*i*) positive, (*ii*) negative. *[CBSE Sample Paper 2016]*

Ans. (*i*) Copper (Cu) (Temperature coefficient of resistivity (α) is positive for metals and alloys.)

(*ii*) Silicon (Si) (For semiconductors, α is negative)

Q. 12. A cell of emf 'ε' and internal resistance '*r*' draws a current '*I*'. Write the relation between terminal voltage '*V*' in terms of ε, *I* and *r*. *[CBSE Delhi 2013]*

Ans. The terminal voltage $V < \varepsilon$, so $V = \varepsilon - Ir$



Q. 13. Under what condition will the current in a wire be the same when connected in series and in parallel of *n* identical cells each having internal resistance *r* and external resistance *R* ? *[CBSE 2019 (55/4/1)]*

Ans. When internal resistance of cell r is equal to external resistance.

Let n identical cell of internal resistance r connected in series and parallel with external resistance R.

$$I_S = \frac{n\varepsilon}{R + nr} \qquad \text{and} \qquad I_P = \frac{\varepsilon}{R + \frac{r}{n}} = \frac{n\varepsilon}{Rn + r}$$

According to question,

$$I_S = I_P \Rightarrow \frac{n\varepsilon}{R + nr} = \frac{n\varepsilon}{Rn + r}$$

$$\Rightarrow R + nr = Rn + r \quad \Rightarrow \quad nr - r = Rn - R$$

$$\Rightarrow r\,(n-1) = R(n-1)$$

$$\therefore \qquad r = R$$

Q. 14. Two wires, one of copper and the other of manganin, have same resistance and equal thickness. Which wire is longer? Justify your answer. **[*CBSE Guwahati 2015*]**

Ans. Let l_1 and l_2 be lengths of copper and manganin wires having same resistance R and thickness *i.e.*, area of cross-section (A).

Resistance of copper wire, $R = \dfrac{\rho_1 l_1}{A}$

Resistance of manganin wire $R = \dfrac{\rho_2 l_2}{A}$

$\Rightarrow \qquad \rho_1 l_1 = \rho_2 l_2$ (As ρl = constant)

Since $\rho_1 <<< \rho_2$ Then, $l_1 >>> l_2$

Hence, copper wire would be longer.

Q. 15. Two wires one of manganin and the other of copper have equal length and equal resistance. Which one of these wires will be thicker? **[*CBSE (AI) 2012, (South) 2016*] [*HOTS*]**

Ans. Resistance $R = \dfrac{\rho l}{A} = \dfrac{\rho l}{\pi r^2}$

Resistivity ρ of manganin is much greater than that of copper, therefore to keep same resistance for same length of wire, the manganin wire must be thicker.

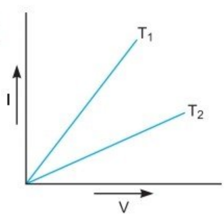
Q. 16. Nichrome and copper wires of same length and same radius are connected in series. Current *I* is passed through them. Which wire gets heated up more? Justify your answer. **[*CBSE (AI) 2017*]**

Ans.

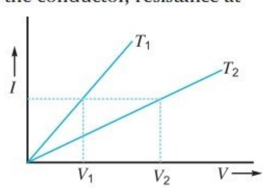
5. I is same in both
when I constant
The heat produced in time t
$H = I^2Rt$
$H \propto R$
$R \propto \rho$ ρ is higher for nichrome
So R is higher for nichrome.
More heat is produced in Nichrome wire.

[*Topper's Answer 2017*]

Q. 17. *I – V* graph for a metallic wire at two different temperatures, T_1 and T_2 is as shown in the figure. Which of the two temperatures is lower and why? **[*CBSE Allahabad 2015*]**



Ans. If a constant current I flows through the conductor, resistance at temperature T_1 and T_2 is



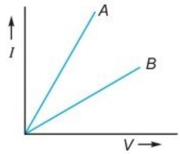
$$R_1 = \frac{V_1}{I}$$

and $$R_2 = \frac{V_2}{I}$$

Since $V_2 > V_1 \quad \Rightarrow \quad R_2 > R_1$

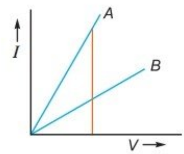
The resistance of the wire increases with rise of temperature. Hence, T_1 is lower than T_2.

Q. 18. Two metallic resistors are connected first in series and then in parallel across a dc supply. Plot of I –V graph is shown for the two cases. Which one represents a parallel combination of the resistors and why? [*CBSE Bhubaneshwer 2015*]



Ans. Line A represents the parallel combination.

Reason: At a given potential difference V, current in the combination A is more than in the combination B.



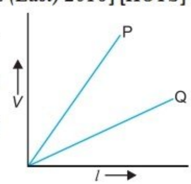
i.e., $I_A > I_B$

Since $R_A = \dfrac{V}{I_A}$ and $R_B = \dfrac{V}{I_B}$

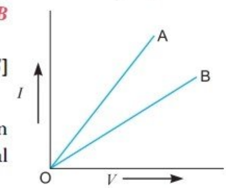
$\Rightarrow \quad R_A < R_B$

Q. 19. The variation of potential difference V with length l in the case of two potentiometer P and Q is as shown. Which of these two will you prefer for comparing the emfs of two primary cells and why? [*CBSE (East) 2016*] [*HOTS*]

Ans. For greater accuracy of potentiometer, the potential gradient (slope) $\dfrac{V}{l}$ must be as small as possible. In the graph given the slope $\dfrac{V}{l}$ is smaller for a potentiometer Q; hence we shall prefer potentiometer Q for comparing the emfs of two cells.



Q. 20. I – V graph for two identical conductors of different materials A and B is shown in the figure. Which one of the two has higher resistivity? [*CBSE (Chennai) 2015*] [*HOTS*]



Ans. The resistivity of material B is higher.

Reason: If the same amount of the current flows through them, then $V_B > V_A$, and from Ohm's law $R_B > R_A$. Hence the resistivity of the material B is higher.

Q. 21. For household electrical wiring, one uses Cu wires or Al wires. What considerations are kept in mind? [*NCERT Exemplar*]

Ans. Two considerations are required: (*i*) cost of metal, and (*ii*) good conductivity of metal. Cost factor inhibits silver. Cu and Al are the next best conductors.

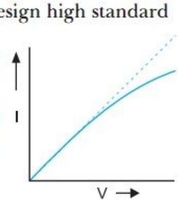
Q. 22. Why are alloys used for making standard resistance coils? [*NCERT Exemplar*]

Ans. Alloys have

(*i*) low value of temperature coefficient and the resistance of the alloy does not vary much with rise in temperature.

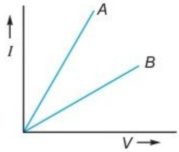
(*ii*) high resistivity, so even a smaller length of the material is sufficient to design high standard resistance.

Q. 23. The *I-V* characteristics of a resistor are observed to deviate from a straight line for higher values of current as shown in the adjoining figure why? [*HOTS*]

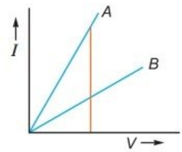


Ans. At higher value of current, sufficient heat is produced which raises the temperature of resistor and so causes increase in resistance.

Q. 18. Two metallic resistors are connected first in series and then in parallel across a dc supply. Plot of I –V graph is shown for the two cases. Which one represents a parallel combination of the resistors and why? *[CBSE Bhubaneshwer 2015]*



Ans. Line A represents the parallel combination.



Reason: At a given potential difference V, current in the combination A is more than in the combination B.

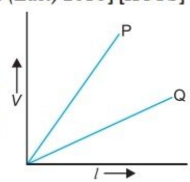
i.e., $I_A > I_B$

Since $R_A = \dfrac{V}{I_A}$ and $R_B = \dfrac{V}{I_B}$

$\Rightarrow \quad R_A < R_B$

Q. 19. The variation of potential difference V with length l in the case of two potentiometer P and Q is as shown. Which of these two will you prefer for comparing the emfs of two primary cells and why? *[CBSE (East) 2016]* [*HOTS*]

Ans. For greater accuracy of potentiometer, the potential gradient (slope) $\dfrac{V}{l}$ must be as small as possible. In the graph given the slope $\dfrac{V}{l}$ is smaller for a potentiometer Q; hence we shall prefer potentiometer Q for comparing the emfs of two cells.



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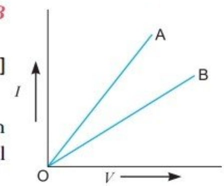

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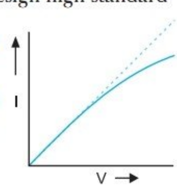
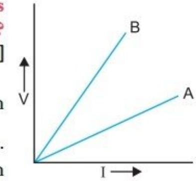


Ans. At higher value of current, sufficient heat is produced which raises the temperature of resistor and so causes increase in resistance.

Q. 24. *V-I* graphs for parallel and series combinations of two metallic resistors are shown in figure. Which graph represents parallel combination? Justify your answer. ***[HOTS]***



Ans. Graph '*A*' represents parallel combination.

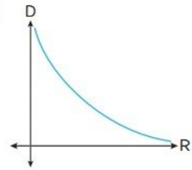
Reason: In series combination the effective resistance, $R = \dfrac{V}{I}$ is more than parallel combination. The slope of a line of *V-I* graph represents resistance. The slope of *B* is more than *A*. Therefore *B* represents series combination and A represents parallel combination.

Q. 25. Draw a graph to show a variation of resistance of a metal wire as a function of its diameter keeping its length and material constant. ***[CBSE Sample Paper 2017]***

Ans. $R = \rho\dfrac{1}{A} \quad \Rightarrow \quad \rho\dfrac{l}{\pi r^2} = \rho\dfrac{4l}{\pi D^2}$

i.e. $\quad R \propto \dfrac{1}{D^2}$

Hence, graph of resistance (R) versus diameter (D) is of the following form.



Very Short Answer Questions

Each of the following questions are of 2 marks.

Q. 1. Define the terms (*i*) drift velocity, (*ii*) relaxation time. ***[CBSE Delhi 2011, (AI) 2013]***

Ans. (*i*) **Drift Velocity:** The average velocity acquired by the free electrons of a conductor in a direction opposite to the externally applied electric field is called drift velocity. The drift velocity will remain the same with lattice ions/atoms.

(*ii*) **Relaxation Time:** The average time of free travel of free electrons between two successive collisions is called the **relaxation time**.

Q. 2. Define the term 'mobility' of charge carriers in a current carrying conductor. Obtain the relation for mobility in terms of relaxation time. ***[CBSE 2020 (55/2/1)]***

Ans.

(21) The drift velocity attained by the charge carries in unit electric field is defined as 'mobility' of charge carries in a current-carrying conductor.

$\therefore$ mobility $(\mu) = \dfrac{v_d}{E}$ 1

We know, drift velocity, $v_d = a\tau$, where τ is relaxation time, and a is acceleration of the charge carrier.

Now, in presence of electric field E, acceleration 'a' of a charged particle of charge 'e' $= \dfrac{eE}{m}$

$\therefore v_d = \dfrac{eE\tau}{m}$

$\Rightarrow \dfrac{v_d}{E} = \dfrac{e\tau}{m} \Rightarrow \boxed{\mu = \dfrac{e\tau}{m}}$

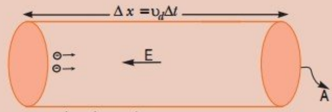
$\therefore$ μ is charge times relaxation time divided by mass of the particle m.

[Topper's Answer 2020]

Q. 3. Define the term 'drift velocity' of electrons in a current carrying conductor. Obtain the relationship between the current density and the drift velocity of electrons. [*CBSE 2020 (55/2/1)*]

Ans. The average speed with which electrons move when an electric field or potential difference is applied is called drift velocity. **1**

$$\vec{v}_d = \frac{-e\vec{E}\tau}{m}$$



The amount of charge crossing the area A in time Δt **½**

$$I\Delta t = ne\,A\left|\vec{v}_d\right|\Delta t$$

Hence current density **½**

$$j = \frac{I}{A} = ne\,v_d$$

[*CBSE Marking Scheme 2020 (55/2/1)*]

Q. 4. Differentiate between the random velocity and the drift velocity of electrons in an electrical conductor. Give their order of magnitudes. [*CBSE 2020 (55/3/1)*]

Ans. **1**

	Random Velocity (v)	**Drift Velocity (v_d)**
1.	The velocity acquired by the free electrons in the absence of electric field.	The average velocity acquired by the free electrons in the presence of electric field.
2.	The average ramdom velocity is zero.	The average drift velocity is not zero.
3.	Has quite a large value.	Has a very small value.

Order of magnitude of random velocity in 10^2 m/s. **½ + ½**

Order of magnitude of drift velocity is 10^{-3} m/s. [*CBSE Marking Scheme 2020 (55/3/1)*]

Q. 5. A battery of emf 12 V and internal resistance 4 Ω is connected to an external resistance *R*. If the current in the resistance is 0.5 A, calculate the value of (*a*) *R*, and (*b*) the terminal voltage of the battery. [*CBSE 2020 (55/3/2)*]

Ans. Current, $I = \frac{E}{R+r}$

$\Rightarrow \quad E = I(R + r)$

$\Rightarrow \quad 12 = 0.5\,(R + 4)$

$\therefore \quad R = 24 - 4 = 20\,\Omega$

Terminal voltage across the battery,

$$V_T = E - Ir = 12 - 0.5 \times 4 = \mathbf{10\ V}$$

Q. 6. Write two differences between the emf and terminal potential difference of a cell. What is the most important precaution that one should take while drawing current from a cell? [*CBSE 2023 (55/4/1)*]

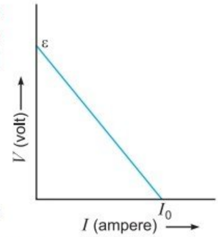
Ans.

EMF	**Terminal Potential Difference (T.P.D)**
(*i*) EMF is the maximum potential difference that a cell is able to produce when there is no current flow across it.	(*i*) Terminal voltage is the potential difference across of the terminals when the circuit is switched on.
(*ii*) EMF is measured using a potentiometer.	(*ii*) It is measured using voltmeter.
(*iii*) The value of EMF is always greater than *T.P.D* due to open circuit.	(*iii*) The value of *T.P.D* is always lower than that of EMF due to the potential drop.

Precaution: (1) Some external resistance should be connected to cell in series.

(2) Short circuiting should be avoided.

Q. 7. Plot a graph showing variation of voltage verses the current drawn from the cell. How can one get information from this plot about the emf of the cell and its internal resistance? **[*CBSE (F) 2016*]**



Ans. $V = \varepsilon - Ir \Rightarrow r = \dfrac{\varepsilon - V}{I}$

At $I = 0, V = \varepsilon$

When $V = 0,\quad I = I_{0,}\ r = \dfrac{\varepsilon}{I_0}$

The intercept on y-axis gives the emf of the cell. The slope of graph gives the internal resistance.

Q. 8. Two cells of emfs 1.5 V and 2.0 V having internal resistances 0.2 Ω and 0.3 Ω respectively are connected in parallel. Calculate the emf and internal resistance of the equivalent cell. **[*CBSE Delhi 2016*]**

Ans. Given, $E_1 = 1.5\text{ V},\quad r_1 = 0.2\,\Omega$

$E_2 = 2.0\text{ V},\quad r_2 = 0.3\,\Omega$

Emf of equivalent cell,

$$E = \frac{\dfrac{E_1}{r_1} + \dfrac{E_2}{r_2}}{\dfrac{1}{r_1} + \dfrac{1}{r_2}} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2} = \left(\frac{1.5 \times 0.3 + 2 \times 0.2}{0.2 + 0.3}\right) = \frac{0.45 + 0.40}{0.5}\text{V} = \mathbf{1.7\ V}$$

Internal resistance of equivalent cell,

$$\frac{1}{r} = \frac{1}{r_1} + \frac{1}{r_2} \Rightarrow r = \frac{r_1 r_2}{r_1 + r_2} = \left(\frac{0.2 \times 0.3}{0.2 + 0.3}\right)\Omega = \frac{0.06}{0.5}\Omega = \mathbf{0.12\,\Omega}$$

Q. 9. When 5 V potential difference is applied across a wire of length 0.1 m, the drift speed of electrons is 2.5×10^{-4} m/s. If the electron density in the wire is 8×10^{28} m^{-3}, calculate the resistivity of the material of wire. **[*CBSE (North) 2016*]**

Ans. We know $I = neAv_{d,}\ I = \dfrac{V}{R}$ and $R = \rho\dfrac{l}{A}$

So $\quad \dfrac{V}{R} = neAv_d$

$$\frac{V}{nev_d\,l} = \frac{RA}{l} \Rightarrow \rho = \frac{V}{nev_d\,l}$$

$$\rho = \frac{5}{8 \times 10^{28} \times 1.6 \times 10^{-19} \times 2.5 \times 10^{-4} \times 0.1}\Omega\text{m} = 1.56 \times 10^{-5}\,\Omega\text{m}$$

$$\approx \mathbf{1.6 \times 10^{-5}\,\Omega m}$$

Q. 10. Two conducting wires *X* and *Y* of same diameter but different materials are joined in series across a battery. If the number density of electrons in *X* is twice that in *Y*, find the ratio of drift velocity of electrons in the two wires. **[*CBSE (AI) 2011*]**

Ans. In series current is same,

So, $\quad I_X = I_Y = I = neAv_d$

For same diameter, cross-sectional area is same

$A_X = A_Y = A$

$\therefore \quad I_X = I_Y \quad \Rightarrow \quad n_x eAv_x = n_y eAv_y$

Given $\quad n_x = 2n_y \quad \Rightarrow \quad \dfrac{v_x}{v_y} = \dfrac{n_y}{n_x} = \dfrac{n_y}{2n_y} = \mathbf{\dfrac{1}{2}}$

Q. 11. A potential difference V is applied across the ends of copper wire of length l and diameter D. What is the effect on drift velocity of electrons if **[*CBSE Ajmer 2015*]**

(*i*) V is halved? **(*ii*) l is doubled?**

(*iii*) D is halved?

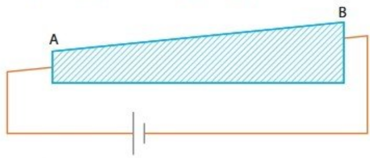
Ans. Drift velocity, $v_d = \dfrac{I}{neA} = \dfrac{V/R}{neA} = \dfrac{V}{neA\left(\dfrac{\rho l}{A}\right)} = \dfrac{V}{ne\rho\, l}$

(*i*) As $v_d \propto V$, when V is halved the drift velocity is halved.

(*ii*) As $v_d \propto \dfrac{1}{l}$, when l is doubled the drift velocity is halved.

(*iii*) As v_d is independent of D, when D is halved drift velocity remains unchanged.

Q. 12. A steady current flows through a wire AB, as shown in the figure. What happens to the electric field and the drift velocity along the wire? Justify your answer. **[*CBSE 2023 (55/4/1)*]**



Ans. According to Ohm's Law, $J = \sigma E$

So, $J \propto E \;\Rightarrow\; E \propto \dfrac{1}{A}$

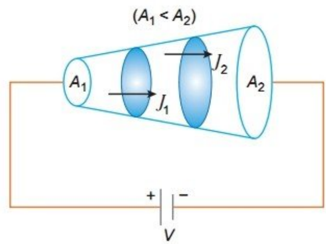
Along the wire if A increases then E will decreases.

Drift velocity, $v_d = \mu E$

(Here, μ = constant)

$v_d \propto E \Rightarrow v_d \propto \dfrac{1}{A}$

Similarly, if A increases v_d will decreases.



Q. 13. A wire of length L_0 has a resistance R_0. It is gradually stretched till its length becomes 2 L_0.

(*a*) Plot a graph showing variation of its resistance R with its length L during stretching.

(*b*) What will be its resistance when its length becomes $2L_0$? **[*CBSE 2020 (55/4/1)*]**

Ans. (*a*) Intially, $R_0 = \dfrac{\rho L_0}{A_0}$

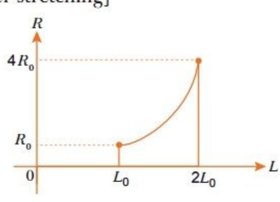
On stretching, the total volume is constant

$A_0 L_0 = AL$ [Where A and L are area and length after stretching]

$$A = \frac{L_0 A_0}{L}$$

$$\frac{R}{R_0} = \frac{\rho L}{A}\frac{A_0}{\rho L_0} = \frac{L}{\dfrac{L_0 A_0}{L}}\frac{A_0}{L_0} = \frac{L^2 A_0}{L_0^2 A_0} = \frac{L^2}{L_0^2}$$

$$R = R_0\left(\frac{L}{L_0}\right)^2 \Rightarrow R \propto L^2$$

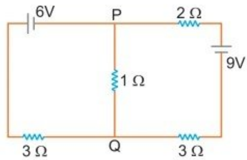


(*b*) When $L = 2L_0$

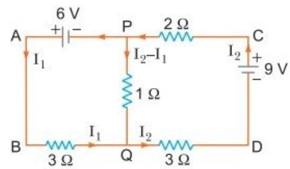
$R = 4\,R_0$

Q. 14. Find the magnitude and direction of current in 1Ω resistor in the given circuit.

[*CBSE (South) 2016*]



Ans. For the mesh *APQBA*



$$-6 - 1(I_2 - I_1) + 3I_1 = 0$$

or $$-I_2 + 4I_1 = 6 \quad ...(i)$$

For the mesh *PCDQP*

$$2I_2 - 9 + 3I_2 + 1(I_2 - I_1) = 0$$

or $$6I_2 - I_1 = 9 \quad ...(ii)$$

Solving (*i*) and (*ii*), we get

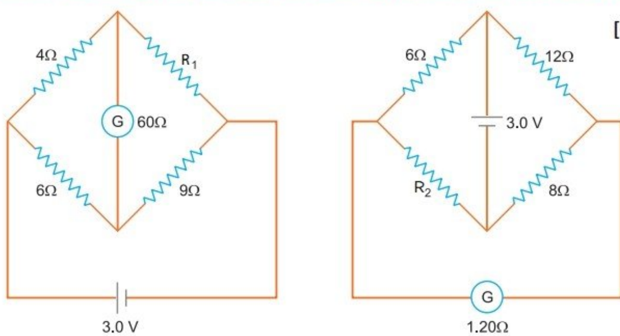
$$I_1 = \frac{45}{23}\text{A} \quad \text{and} \quad I_2 = \frac{42}{23}\text{A}$$

$\therefore$ Current through the 1 Ω resistor $= (I_2 - I_1) = \mathbf{\frac{-3}{23}A}$

Hence the direction of current in 1 Ω resistor from *Q* to *P* in the circuit.

Q. 15. Figure shows two circuits each having a galvanometer and a battery of 3 V. When the galvanometers in each arrangement do not show any deflection, obtain the ratio $\frac{R_1}{R_2}$.

[*CBSE (AI) 2013*]



Ans. For balanced Wheatstone bridge, no current flows through the galvanometer.

$$\frac{4}{R_1} = \frac{6}{9}$$

$\Rightarrow$ $$R_1 = \frac{4 \times 9}{6} = 6\ \Omega$$

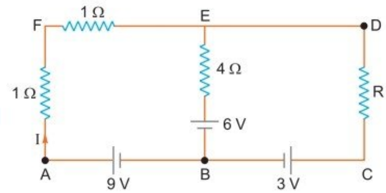
For another circuit,

$$\frac{6}{12} = \frac{R_2}{8} \Rightarrow R_2 = \frac{6 \times 8}{12} = 4\ \Omega$$

$$\therefore \text{ Ratio, } \frac{R_1}{R_2} = \frac{6}{4} = \mathbf{\frac{3}{2}}$$

Q. 16. Using Kirchoff's rules determine the value of unknown resistance R in the circuit so that no current flows through 4 Ω resistance. Also find the potential difference between A and D.

[*CBSE Delhi 2012*] [*HOTS*]



Ans. Applying Kirchhoff's loop rule for loop $ABEFA$,

$$-9 + 6 + 4 \times 0 + 2I = 0$$

$$I = 1.5 \text{ A} \qquad ...(i)$$

For loop $BCDEB$

$$3 + IR + 4 \times 0 - 6 = 0$$

$$\therefore \qquad IR = 3$$

Putting the value of I from (i) we have

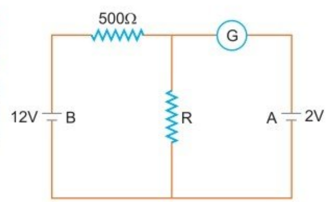
$$\frac{3}{2} \times R = 3 \;\Rightarrow\; R = 2\Omega$$

Potential difference between A and D through path $ABCD$,

$$9 - 3 - IR = V_{AD}$$

or $$9 - 3 - \frac{3}{2} \times 2 = V_{AD} \quad \Rightarrow \quad V_{AD} = \mathbf{3\ V}$$

Q. 17. In the circuit shown in the figure, the galvanometer 'G' gives zero deflection. If the batteries A and B have negligible internal resistance, find the value of the resistor R. **[*CBSE (F) 2013*] [*HOTS*]**



Ans. If galvanometer G gives zero deflection, than current of source of 12 V flows through R, and voltage across R becomes 2 V.

Current in the circuit $I = \dfrac{\varepsilon}{R_1 + R_2} = \dfrac{12}{500 + R}$

and $$V = IR = 2$$

$$\left(\frac{12.0}{500 + R}\right) R = 2$$

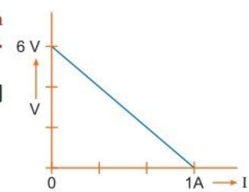
$$\Rightarrow \qquad 12R = 1000 + 2R$$

$$\Rightarrow \qquad 10R = 1000$$

$$\therefore \qquad R = \mathbf{100\ \Omega}$$

Q. 18. The plot of the variation of potential difference across a combination of three identical cells in series, versus current is shown alongside. What is the emf and internal resistance of each cell?

[*CBSE (Central) 2016*] [*HOTS*]



Ans. We know that for a circuit

$$V = E_{eq} - Ir_{eq} \qquad ...(i)$$

From graph, when $I = 0$ A, then $V = 6$ V and when $I = 1$ A then $V = 0$ V

Putting, $V = 6$ V and $I = 0$ A in eq. (i)

$$6 = E_{eq} - 0.\, r_{eq} \quad \Rightarrow \quad E_{eq} = 6 \text{ V}$$

$$E_{eq} = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 \Rightarrow \quad \varepsilon_1 = \varepsilon_2 = \varepsilon_3 = \varepsilon = \frac{E_{eq}}{3} = 2 \text{ V}$$

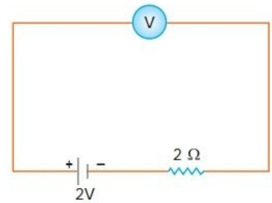
And, when $I = 1$ A, and $V = 0$ V

$$0 = 6 - 1.\, r_{eq} \quad \Rightarrow \quad r_{eq} = 6\ \Omega$$

$$r_{eq} = r_1 + r_2 + r_3 \Rightarrow \quad r_1 = r_2 = r_3 = r = \frac{r_{eq}}{3} = \mathbf{2\ \Omega}$$

Q. 19. A voltmeter of resistance 998 Ω is connected across a cell of emf 2 V and internal resistance 2 Ω. Find the potential difference across the voltmeter and also across the terminals of the cell. Estimate the percentage error in the reading of the voltmeter. *[CBSE 2019 (55/5/1)]*

Ans. We have, $V = E - Ir$



$\Rightarrow \quad 998 \times I = 2 - 2I$

$\Rightarrow \quad 1000 \times I = 2$

$\therefore \quad I = \dfrac{2}{1000} = 0.002 \text{ A}$

Now, $V = 0.002 \times 998$

$V = 1.996 \text{ V}$

Then $\Delta V = 2 - 1.996$

$= 0.004 \text{ V}$

$\therefore \quad \% \text{ error} = \dfrac{0.004}{2} \times 100 = \mathbf{0.2\%}$

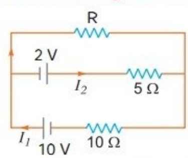
Q. 20. Two wires *A* and *B* of the same material and having same length, have their cross sectional areas in the ratio 1 : 6. What would be the ratio of heat produced in these wires when same voltage is applied across each? *[CBSE Sample Paper 2017]*

Ans. As given, $A_A : A_B = 1 : 6$

$H = V^2t/R$ and $R = \dfrac{\rho l}{A}$

$$H_A = \frac{V^2t}{\rho l/A_A}; \quad H_B = \frac{V^2t}{\rho l/A_B} \Rightarrow \frac{H_A}{H_B} = \frac{V^2t \times A_A}{\rho l} \times \frac{\rho l}{V^2tA_B} \Rightarrow \frac{H_A}{H_B} = \frac{A_A}{A_B} = \mathbf{1:6}$$

Q. 21. Two cells of emf 10 V and 2 V and internal resistance 10 Ω and 5 Ω respectively, are connected in parallel as shown. Find the effective voltage across *R*. *[CBSE Sample Paper 2016]*

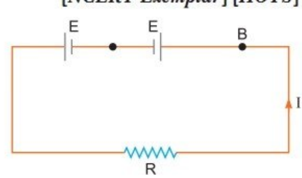


Ans. The effective voltage across *R* is given by $\varepsilon_{eq} = \dfrac{\left(\dfrac{\varepsilon_1}{r_1} + \dfrac{\varepsilon_2}{r_2}\right)}{\left(\dfrac{1}{r_1} + \dfrac{1}{r_2}\right)} = \dfrac{\left(\dfrac{10}{10} - \dfrac{2}{5}\right)}{\left(\dfrac{1}{10} + \dfrac{1}{5}\right)}$

$\therefore \quad \varepsilon_{eq} = \mathbf{2 \text{ V}}$

Q. 22. Two cells of same emf *E* but internal resistance r_1 and r_2 are connected in series to an external resistor *R* (Fig.). What should be the value of *R* so that the potential difference across the terminals of the first cell becomes zero. *[NCERT Exemplar] [HOTS]*

Ans. From the circuit shown, $I = \dfrac{E + E}{R + r_1 + r_2}$



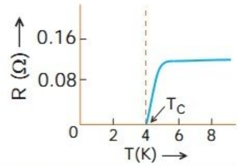
$V_1 = E - Ir_1 = E - \dfrac{2E}{r_1 + r_2 + R} r_1 = 0$

or $\quad E = \dfrac{2Er_1}{r_1 + r_2 + R}$

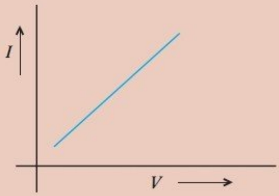
$\Rightarrow \quad r_1 + r_2 + R = 2r_1 \Rightarrow R = \mathbf{r_1 - r_2}$

Q. 23. **(*a*) Draw a graph showing the variation of current versus voltage voltage in an electrolyte when an external resistance is also connected.**

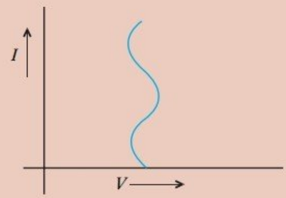
(*b*) The graph between resistance (*R*) and temperature (*T*) for Hg is shown in the figure. Explain the behaviour of Hg near 4K. [*CBSE 2019 (55/4/1)*]



Ans. (*a*) Note : Award this 1 mark even if the student draw the following or some other non linear graph **1**



OR



(*b*) At a temperature of 4 K, the resistance of Hg becomes zero. **1**

Note - Award this 1 mark if the student writes that Hg becomes a super conductor at temperature of 4 K

[*CBSE Marking Scheme 2019 (55/4/1)*]

Q. 24. **At room temperature (27.0°C), the resistance of a heating element is 100 Ω. At what temperature does the resistance of the element change to 117 Ω? Given that the temperature coefficient of the material of the resistor is 1.70×10^{-4} °C^{-1}.** [*NCERT*]

Ans. Given, $R_{27} = 100\ \Omega$, $R_t = 117\ \Omega$, $t = ?$, $\alpha = 1.70 \times 10^{-4}/°C$

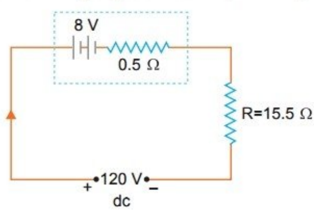
Temperature Coefficient, $\alpha = \dfrac{R_t - R_{27}}{R_{27}(t-27)}$, temperature t is unknown

$$\Rightarrow \quad t - 27 = \frac{R_t - R_{27}}{R_{27}.\alpha} = \frac{117-100}{100 \times 1.70 \times 10^{-4}} = 1000$$

$$\Rightarrow \quad t = 1000 + 27 = \mathbf{1027°C}$$

Q. 25. **A storage battery of emf 8.0 V and internal resistance 0.5 Ω is being charged by a 120 V dc supply using a series resistor of 15.5 Ω. What is the terminal voltage of the battery during charging? What is the purpose of having a series resistor in the charging circuit?** [*NCERT*]

Ans. When battery is being charged by a 120 V d.c. supply, the current in battery is in opposite direction than normal connections of battery of supplying current. So the potential difference across battery



$$E = V + IR$$

Given $E = 8$ V, $r = 0.5\ \Omega$, $R = 15.5\ \Omega$

Current in circuit, $I = \dfrac{120-8}{15.5+0.5} = \dfrac{112}{16} = 7$ A

$$\therefore \quad V = 8 + 7 \times 0.5 = \mathbf{11.5\ V}$$

Series resistance limits the current drawn from external dc source. In the absence of series resistance the current may exceed the safe-value permitted by storage battery.

Short Answer Questions

Each of the following questions are of 3 marks.

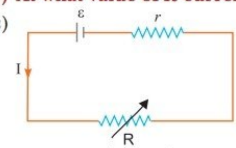
Q. 1. A variable resistor R is connected across a cell of emf E and internal resistance r.

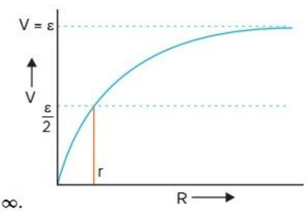
(a) Draw the circuit diagram.

(b) Plot the graph showing variation of potential drop across R as function of R.

(c) At what value of R current in circuit will be maximum? [*CBSE Sample Paper 2021*]

Ans. (a)





(b) $V = IR = \left(\dfrac{\varepsilon}{R+r}\right)R = \dfrac{\varepsilon}{(R+r)/R} = \dfrac{\varepsilon}{1+\dfrac{r}{R}}$

(c) Maximum current is drawn when $R = 0$, $I = \dfrac{V}{R} = \dfrac{V}{0} = \infty$.

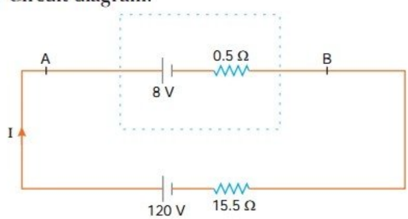
Q. 2. A storage battery of emf 8 V and internal resistance 0.5 ohm is being charged by d.c. supply of 120 V using a resistor of 15.5 ohm.

(a) Draw the circuit diagram.

(b) Calculate the potential difference across the battery.

(c) What is the purpose of having series resistance in this circuit? [*CBSE Sample Paper 2021*]

Ans. (a) Circuit diagram:



(b) $I_{net} = \dfrac{V_{net}}{R+r} = \dfrac{120-8}{15.5+0.5} = \dfrac{112}{16} = 7\text{A}$

Applying Kirchoff's rule,

$$V_B + 0.5(7) + 8 = V_A$$

$$3.5 + 8 = 11.5 = V_A - V_B$$

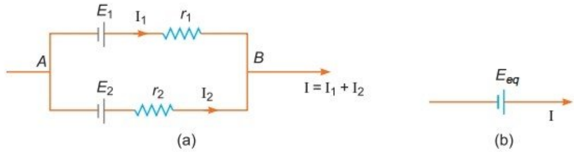
$\therefore$ Potential difference, $V_A - V_B = \mathbf{11.5\ V}$

(c) Series resistance limits the current through the source.

Q. 3. (a) Two cells of emf E_1 and E_2 have their internal resistances r_1 and r_2, respectively. Deduce an expression for the equivalent emf and internal resistance of their parallel combination when connected across an external resistance R. Assume that the two cells are supporting each other.

(b) In case the two cells are identical, each of emf $E = 5$ V and internal resistance $r = 2\ \Omega$, calculate the voltage across the external resistance $R = 10\ \Omega$. [*CBSE 2020 (55/1/1)*]

Ans. (*a*)



Let I_1 and I_2 be the currents leaving the positive, terminals of the cells, and at the point B

$$I = I_1 + I_2 \qquad ...(i)$$

Let V be the potential difference between points A and B of the combination of the cells, so

$$V = E_1 - I_1 r_1 \qquad ...(ii)$$

and $$V = E_2 - I_2 r_2 \qquad ...(iii)$$

From equation (*i*), (*ii*) and (*iii*), we get

$$I = \frac{(E_1 - V)}{r_1} + \frac{(E_2 - V)}{r_2}$$

$$= \left(\frac{E_1}{r_1} + \frac{E_2}{r_2}\right) - V\left(\frac{1}{r_1} + \frac{1}{r_2}\right) \qquad ...(iv)$$

Fig. (*b*) shows the equivalent cell, so for the same potential difference

$$V = E_{eq} - I r_{eq}$$

or $$I = \frac{E_{eq}}{r_{eq}} - \frac{V}{r_{eq}} \qquad ...(v)$$

On comparing Eq. (*iv*) and (*v*), we get

$$\frac{E_{eq}}{r_{eq}} = \frac{E_1}{r_1} + \frac{E_2}{r_2}$$

and $$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} \quad \Rightarrow \quad r_{eq} = \frac{\boldsymbol{r_1 r_2}}{\boldsymbol{r_1 + r_2}}$$

On further solving, we have

$$E_{eq}\left(\frac{1}{r_1} + \frac{1}{r_2}\right) = \frac{E_1}{r_1} + \frac{E_2}{r_2} \quad \Rightarrow \quad E_{eq} = \frac{\boldsymbol{E_1 r_2 + E_2 r_1}}{\boldsymbol{r_1 + r_2}}$$

(*b*) $E_{eff} = \dfrac{5 \times 2 + 5 \times 2}{2+2} = 5\text{ V}$ and $r_{eff} = \dfrac{2 \times 2}{2+2} = 1\,\Omega$

Now, $I = \dfrac{E_{eff}}{R + r_{eff}} = \dfrac{5}{10+1} = \dfrac{5}{11}\text{A}$

$\therefore$ Voltage across R, $V = IR = \dfrac{5}{11} \times 10 = \dfrac{50}{11}\text{V} = \mathbf{4.54\ V}$

Q. 4. Using the concept of free electrons in a conductor, derive the expression for the conductivity of a wire in terms of number density and relaxation time. Hence obtain the relation between current density and the applied electric field *E*.

Ans. The acceleration, $\vec{a} = -\dfrac{e}{m}\vec{E}$

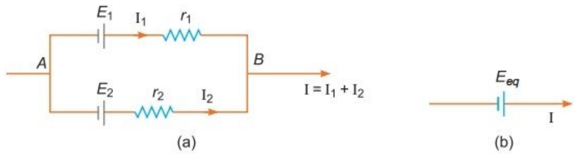
The average drift velocity is given by, $v_d = -\dfrac{eE}{m}\tau$

(τ = average time between collisions or relaxation time)

If n is the number of free electrons per unit volume, the current I is given by

$$I = neA|v_d|$$

Ans. (*a*)



Let I_1 and I_2 be the currents leaving the positive, terminals of the cells, and at the point B

$$I = I_1 + I_2 \quad \text{...}(i)$$

Let V be the potential difference between points A and B of the combination of the cells, so

$$V = E_1 - I_1 r_1 \quad \text{...}(ii)$$

and $$V = E_2 - I_2 r_2 \quad \text{...}(iii)$$

From equation (*i*), (*ii*) and (*iii*), we get

$$I = \frac{(E_1 - V)}{r_1} + \frac{(E_2 - V)}{r_2}$$

$$= \left(\frac{E_1}{r_1} + \frac{E_2}{r_2}\right) - V\left(\frac{1}{r_1} + \frac{1}{r_2}\right) \quad \text{...}(iv)$$

Fig. (*b*) shows the equivalent cell, so for the same potential difference

$$V = E_{eq} - I r_{eq}$$

or $$I = \frac{E_{eq}}{r_{eq}} - \frac{V}{r_{eq}} \quad \text{...}(v)$$

On comparing Eq. (*iv*) and (*v*), we get

$$\frac{E_{eq}}{r_{eq}} = \frac{E_1}{r_1} + \frac{E_2}{r_2}$$

and $$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} \quad \Rightarrow \quad r_{eq} = \frac{\mathbf{r_1 r_2}}{\mathbf{r_1 + r_2}}$$

On further solving, we have

$$E_{eq}\left(\frac{1}{r_1} + \frac{1}{r_2}\right) = \frac{E_1}{r_1} + \frac{E_2}{r_2} \quad \Rightarrow \quad E_{eq} = \frac{\mathbf{E_1 r_2 + E_2 r_1}}{\mathbf{r_1 + r_2}}$$

(*b*) $E_{eff} = \dfrac{5 \times 2 + 5 \times 2}{2 + 2} = 5\text{ V}$ and $r_{eff} = \dfrac{2 \times 2}{2 + 2} = 1\,\Omega$

Now, $I = \dfrac{E_{eff}}{R + r_{eff}} = \dfrac{5}{10 + 1} = \dfrac{5}{11}\text{A}$

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Ans. The acceleration, $\vec{a} = -\dfrac{e}{m}\vec{E}$

The average drift velocity is given by, $v_d = -\dfrac{eE}{m}\tau$

(τ = average time between collisions or relaxation time)

If n is the number of free electrons per unit volume, the current I is given by

$$I = neA|v_d|$$

$$= \frac{e^2 A}{m} \tau n |E|$$

But $I = |j| A$ (where j= current density)

Therefore, we get

$$|j| = \frac{ne^2}{m} \tau |E|.$$

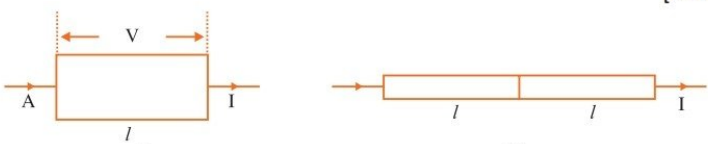
The term $\frac{ne^2}{m}\tau$ is conductivity.

$$\therefore \sigma = \frac{ne^2 \tau}{m}$$

$$\Rightarrow \quad J = \sigma E$$

Q. 5. A metal rod of square cross-sectional area A having length l has current I flowing through it when a potential difference of V volt is applied across its ends (figure (*i*)). Now the rod is cut parallel to its length into two identical pieces and joined as shown in figure (*ii*). What potential difference must be maintained across the length $2l$ so that the current in the rod is still I?

[*CBSE (F) 2016*]



(*i*) (*ii*)

Ans. Let resistance of metal rod having cross sectional area A and length l be R_1

$$\Rightarrow \quad R_1 = \rho \frac{l}{A}$$

Also, resistance of metal rod having cross sectional area $\frac{A}{2}$ and length $2l$

$$R_2 = \rho \frac{2l}{\frac{A}{2}} \qquad \left[\because R = \rho \frac{l}{A}\right]$$

$$= 4 R_1$$

Let V' be potential difference maintained across rod. When the rod is cut parallel and rejoined by length, the length of the conductor becomes $2l$ and area decreases by $\frac{A}{2}$.

For maintaining same current,

$$I = \frac{V}{R_1} = \frac{V'}{R_2}$$

$$I = \frac{V}{R_1} = \frac{V'}{4R_1} \Rightarrow V' = \mathbf{4V}$$

The new potential applied across the metal rod will be four times the original potential (V).

Q. 6. Two metallic wires, P_1 and P_2 of the same material and same length but different cross-sectional areas, A_1 and A_2 are joined together and connected to a source of emf. Find the ratio of the drift velocities of free electrons in the two wires when they are connected (*i*) in series, and (*ii*) in parallel. **[*CBSE (F) 2017*]**

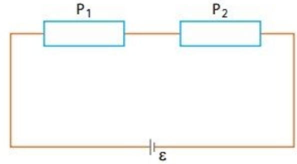
Ans. We know that,

$$I = neAv_d \quad \Rightarrow \quad v_d = \frac{I}{neA}$$

Let R_1 and R_2 be resistances of P_1 & P_2 and A_1 & A_2 are their cross sectional areas respectively.

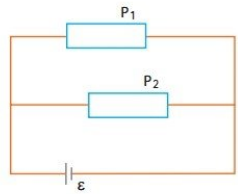
$$\therefore \qquad R_1 = \rho\frac{l}{A_1} \quad \text{and} \quad R_2 = \rho\frac{l}{A_2}$$

(*i*) When connected in series,



$$\therefore \qquad \frac{v_{d_1}}{v_{d_2}} = \frac{\dfrac{\varepsilon}{\left(\dfrac{\rho l}{A_1}+\dfrac{\rho l}{A_2}\right)neA_1}}{\dfrac{\varepsilon}{\left(\dfrac{\rho l}{A_1}+\dfrac{\rho l}{A_2}\right)neA_2}} = \frac{A_2}{A_1}$$

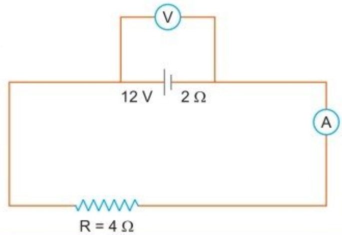
(*ii*) When, connected in parallel,



$$\therefore \frac{v_{d_1}}{v_{d_2}} = \frac{\dfrac{\varepsilon}{\dfrac{\rho l}{A_1}}\cdot\dfrac{1}{neA_1}}{\dfrac{\varepsilon}{\dfrac{\rho l}{A_2}}\cdot\dfrac{1}{neA_2}} = \mathbf{1}$$

Q. 7. (*a*) The potential difference applied across a given resistor is altered so that the heat produced per second increases by a factor of 9. By what factor does the applied potential difference change?

(*b*) In the figure shown, an ammeter *A* and a resistor of 4 Ω are connected to the terminals of the source. The emf of the source is 12 V having an internal resistance of 2 Ω. Calculate the voltmeter and ammeter readings. **[*CBSE (AI) 2017*]**



Ans.

15 (a) Heat per second is $\frac{V^2}{R}$

Initially $H_1 = \frac{V_1^2}{R}$ The R is fixed.

Then $H_2 = 9H_1 = \frac{9V_1^2}{R} = \frac{3^2 V_1^2}{R} = \frac{(3V_1)^2}{R}$.

The potential difference is increased by a factor of 3.

(b) $V = \mathcal{E} - Ir$

Total current $= \frac{\text{Total emf}}{\text{Total resistance}}$

$= \frac{12}{2+4}$

$= \frac{12}{6} = 2A$

The ammeter reading is 2 A

The voltmeter reading is $V = \mathcal{E} - Ir$

$= 12 - 2\times 2$

$= 12 - 4$

$= 8V$

[*Topper's Answer 2017*]

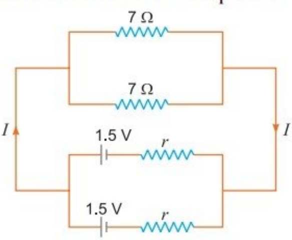
Q. 8. Two identical cells of emf 1.5 V each joined in parallel supply energy to an external circuit consisting of two resistances of 7 Ω each joined in parallel. A very high resistance voltmeter reads the terminal voltage of cells to be 1.4 V. Calculate the internal resistance of each cell.

[*CBSE (North) 2016*]

Ans. Here, $E = 1.5$ V, $V = 1.4$ V

Resistance of external circuit = Equivalent resistance of two resistances of 7Ω connected in parallel

or $$R = \frac{R_1 R_2}{R_1 + R_2} = \frac{7 \times 7}{7 +} \Omega = 3.5\ \Omega R$$



Let r' be the total internal resistance of the two cells, then

$$r' = \left(\frac{E - V}{V}\right) R = \left(\frac{1.5 - 1.4}{1.4}\right) 3.5 = 0.25\ \Omega$$

As the two cells of internal resistance r each have been connected in parallel, so

$$\frac{1}{r'} = + \frac{1}{r}\frac{1}{r'} \Rightarrow \frac{1}{0.25} = \frac{2}{r} \Rightarrow r = 0.252 \times 2 = \mathbf{0.5\ \Omega}$$

Q. 9. Show, on a plot, variation of resistivity of (*i*) a conductor, and (*ii*) a typical semiconductor as a function of temperature.

Using the expression for the resistivity in terms of number density and relaxation time between the collisions, explain how resistivity in the case of a conductor increases while it decreases in a semiconductor, with the rise of temperature. [*CBSE 2019 (55/2/1)*]

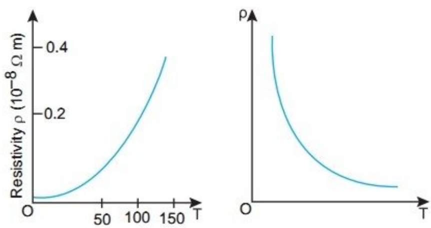
Ans. We know that

$$\rho = \frac{m}{ne^2\tau}$$

Where m is mass of electron

ρ = charge density, τ = relaxation time

e = charge on the electron.

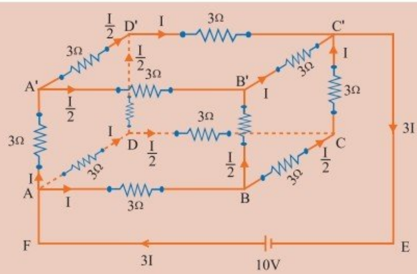


(*i*) In case of conductors with increase in temperature, relaxation time decreases, so resistivity increases.

(*ii*) In case of semiconductors with increase in temperature number density (n) of free electrons increases, hence resistivity decreases.

Q. 10. Twelve wires each having a resistance of 3Ω are connected to form a cubical network. A battery of 10 V and negligible internal resistance is connected across the diagonally opposite corners of this network. Determine its equivalent resistance and the current along each edge of the cube. [*CBSE 2019 (55/3/1)*]

Ans.



½

Applying loop rule to ABCC'EFA,

$$3I + 3\frac{I}{2} + 3I - 10 = 0$$ ½

$$\Rightarrow \quad \frac{15}{2}I = 10$$

$$\therefore \quad I = \frac{2\times 10}{15} = \frac{20}{15}\text{A} = \frac{4}{3}\text{A}$$ ½

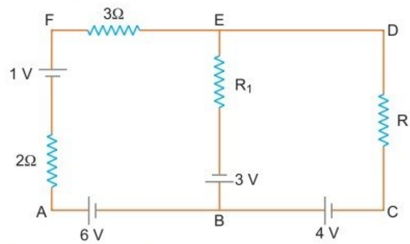
Now, $R_{eq} = \dfrac{V}{3I} = \dfrac{10\times 15}{3\times 20} = 2.5\,\Omega$ ½

Current $= I_{AB}\,(= I_{AA'} = I_{AD} = I_{D'C'} = I_{B'C'} = I_{CC'}) = \dfrac{4}{3}\text{A}$ ½

$I_{DD'}\,(= I_{A'B'} = I_{A'D'} = I_{DC} = I_{BC} = I_{BB'}) = \dfrac{2}{3}\text{A}$ ½

[*CBSE Marking Scheme 2019 (55/3/1)*]

Q. 11. Use Kirchhoff's rules to determine the potential difference between the points *A* and *D* when no current flows in the arm *BE* of the electric network shown in the figure. [*CBSE Allahabad 2015*]



Ans. According to Kirchhoff's junction rule at *E* or *B*

$I_3 = I_2 + I_1$

Since $I_2 = 0$ in the arm *BE* as given in the question

$\Rightarrow \quad I_3 = I_1$

Using loop rule in the loop *AFEBA*

$-2I_3 + 1 - 3I_3 - I_2 R_1 + 3 + 6 = 0$

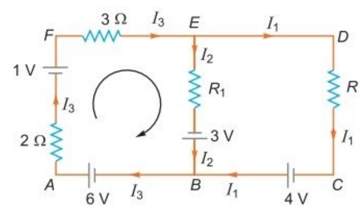
$\Rightarrow \quad 2I_3 + 3I_3 + I_2R_1 = 10$

Since $I_2 = 0$, so

$5I_3 = 10$

$\Rightarrow \quad I_3 = 2$ A

$\therefore \quad I_3 = I_1 = 2$A



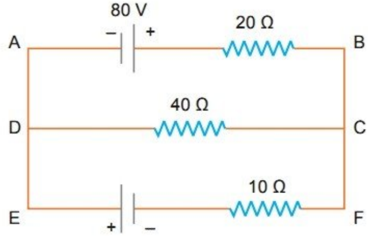
The potential difference between *A* and *D*, along the branch *AFED* of the closed circuit.

$V_A - 2I_3 + 1 - 3\,I_3 - V_D = 0$

$\Rightarrow \quad V_A - V_D = 2I_3 - 1 + 3I_3$

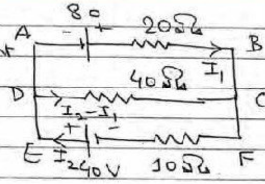
$= 2\times 2 - 1 + 3\times 2 = \mathbf{9\ V}$

Q. 12. Using Kirchhoff's rules, calculate the current through the 40 Ω and 20 Ω resistors in the following circuit. [*CBSE 2019 (55/1/2)*]



Ans.

16. Distributing the current as shown using Kirchhoff's junction rule at all the junctions



Now applying Kirchhoff's ~~voltage~~ loop rule in the loop ABCDA

$$80 - 20I_1 + 40(I_2 - I_1) = 0$$
$$80 = 20I_1 + 40I_1 - 40I_2$$
$$80 = 60I_1 - 40I_2$$
$$\text{OR} \quad 4 = 3I_1 - 2I_2 \quad \text{—(1)}$$

Now, applying Kirchhoff's loop rule in the loop DCFED,

$$-40(I_2 - I_1) - 10I_2 + 40 = 0$$
$$\text{OR} \quad 40 = 10I_2 + 40I_2 - 40I_1$$
$$\text{OR} \quad 4 = 5I_2 - 4I_1 \quad \text{—(2)}$$

Solving (1) & (2),

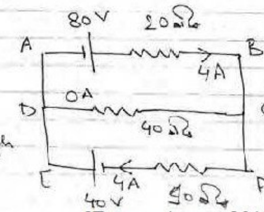
$$\cancel{8 = 6I_1 - 4I_2}$$
$$16 = 12I_1 - 8I_2 \quad \text{(From (1))}$$
$$\text{and } 12 = 15I_2 - 12I_1 \quad \text{(From (2))}$$
$$\text{(Adding)}$$
$$28 = 7I_2$$
$$\text{OR} \quad I_2 = 4\text{ A} \quad \text{—(3)}$$

and from (1),

$$4 = 3I_1 - 2I_2$$
$$4 = 3I_1 - 2(4)$$
$$\text{OR} \quad I_1 = 4\text{ A}$$

So, the circuit becomes.

Hence, no current flows through inner 40 ohm resistor and 4A ~~goes~~ flows ~~from~~ through rest of the resistors.



[*Toppers Answer 2019*]

Q. 13. The potential difference across a resistor '*r*' carrying current '*I*' is *Ir*.

(*i*) Now if the potential difference across '*r*' is measured using a voltmeter of resistance 'R_V', show that the reading of voltmeter is less than the true value.

(*ii*) Find the percentage error in measuring the potential difference by a voltmeter.

(*iii*) At what value of R_V, does the voltmeter measures the true potential difference?

[*CBSE Sample Paper 2016*] [*HOTS*]

Ans. (*i*) $V = Ir$ (without voltmeter R_V)

$$V' = \frac{IrR_V}{r + R_V} = \frac{Ir}{1 + \frac{r}{R_V}}$$

$$V' < V$$

(*ii*) Percentage error $\left(\frac{V - V'}{V}\right) \times 100 = \left(\frac{r}{r + R_V}\right) \times 100$

(*iii*) $R_V \to \infty$, $V' = Ir = V$

Q. 14. A heating element using nichrome connected to a 230 V supply draws an initial current of 3.2 A which settles after a few seconds at a steady value of 2.8 A. What is the steady temperature of the heating element if the room temperature is 27°C? Temperature coefficient of resistance of nichrome averaged over the temperature range involved is 1.7×10^{-4} per °C. [*NCERT*] [*HOTS*]

Ans. Resistance of heating element at room temperature $t_1 = 27°$ C is

$$R_1 = \frac{V}{I_1} = \frac{230}{3.2}\Omega$$

Resistance of heating element at steady state temperature t_2°C is

$$R_2 = \frac{V}{I_2} = \frac{230}{2.8}\Omega$$

Temperature coefficient of resistance $\alpha = \frac{R_2 - R_1}{R_1 \times (t_2 - t_1)}$

$$\therefore \quad t_2 - t_1 = \frac{R_2 - R_1}{R_1 . \alpha} = \frac{\left(\frac{230}{2.8}\right) - \left(\frac{230}{3.2}\right)}{\frac{230}{3.2} \times 1.7 \times 10^{-4}} = \frac{3.2 - 2.8}{2.8 \times 1.7 \times 10^{-4}} = 840.3°\text{C}$$

$\therefore$ Steady state temperature, $t_2 = 840.3 + t_1 = 840.3 + 27 = \mathbf{867.3°C}$

CONSTRUCTED RESPONSE QUESTIONS AS PER NEP

Long Answer Questions

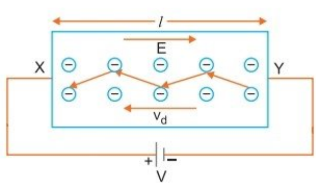
Each of the following questions are of 5 marks.

Q. 1. Derive an expression for drift velocity of free electrons in a conductor in terms of relaxation time of electrons. [*CBSE Delhi 2009*]

OR

Explain how the average velocity of free electrons in a metal at constant temperature, in an electric field, remains constant even though the electrons are being constantly accelerated by this electric field.

Ans. Consider a metallic conductor *XY* of length l and cross-sectional area A. A potential difference V is applied across the conductor *XY*. Due to this potential difference an electric field $\vec{E}$ is produced in the conductor. The magnitude of electric field strength $E = \frac{V}{l}$ and its direction is from *X* to *Y*.



This electric field exerts a force on free electrons; due to which electrons are accelerated.

The electric force on electron $\vec{F} = -e\vec{E}$ (where $e = +1.6 \times 10^{-9}$ coulomb).

If m is the mass of electron, then its acceleration

$$\vec{a} = \frac{\vec{F}}{m} = -\frac{e\vec{E}}{m} \qquad \ldots(i)$$

This acceleration remains constant only for a very short duration, since there are random forces which deflect the electron in random manner. These deflections may arise as

(*i*) ions of metallic crystal vibrate simple harmonically around their mean positions. Different ions vibrate in different directions and may be displaced by different amounts.

(*ii*) direct collisions of electrons with atoms of metallic crystal lattice.

In any way after a short duration called relaxation time, the motion of electrons become random. Thus, we can imagine that the electrons are accelerated only for a short duration. As average velocity of random motion is zero, if we consider the average motion of an electron, then its initial velocity is zero, so the velocity of electron after time τ (*i.e.,* drift velocity $\vec{v}\,d$) is given by the relation $\vec{v} = \vec{u} + \vec{a}\,t$

(here $\vec{u} = 0, v = \vec{v}_d, t = \tau, \vec{a} = -\frac{e\vec{E}}{m}$)

$$\vec{v_d} = 0 - \frac{e\vec{E}}{m}\tau \quad \Rightarrow \vec{v_d} = -\frac{e\tau}{m}\vec{E} \qquad \ldots(ii)$$

At given temperature, the relaxation time τ remains constant, so drift velocity remains constant.

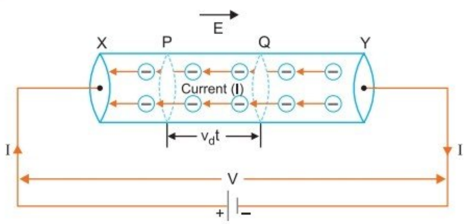
Q. 2. Establish a relation between electric current and drift velocity. [*CBSE (AI) 2013*]

OR

Prove that the current density of a metallic conductor is directly proportional to the drift speed of electrons.

Ans. Relation between electric current and drift velocity:

Consider a uniform metallic wire XY of length l and cross-sectional area A. A potential difference V is applied across the ends X and Y of the wire. This causes an electric field at each point of the wire of strength



$$E = \frac{V}{l}. \qquad \ldots(i)$$

Due to this electric field, the electrons gain a drift velocity v_d opposite to direction of electric field. If q be the charge passing through the cross-section of wire in t seconds, then

$$\text{Current in wire } I = \frac{q}{t} \qquad \ldots(ii)$$

The distance traversed by each electron in time t =average velocity × time = $v_d t$

If we consider two planes P and Q at a distance $v_d\,t$ in a conductor, then the total charge flowing in time t will be equal to the total charge on the electrons present within the cylinder PQ.

The volume of this cylinder = cross sectional area × height

$= A\,v_d\,t$

If n is the number of free electrons in the wire per unit volume, then the number of free electrons in the cylinder $= n\ (Av_d\ t)$

If charge on each electron is $-e$ (e=1.6 $\times 10^{-19}$C), then the total charge flowing through a cross-section of the wire

$$q = (nAv_d t)(-e) = -neAv_d t \qquad ..(iii)$$

$\therefore$ Current flowing in the wire,

$$I = \frac{q}{t} = \frac{-neAv_d t}{t}$$

i.e., current $I = -neAv_d$ ...(*iv*)

This is the relation between electric current and drift velocity. Negative sign shows that the direction of current is opposite to the drift velocity.

Numerically $I = -neAv_d$ ...(*v*)

$\therefore$ Current density, $J = \dfrac{I}{A} = nev_d$

$\Rightarrow$ $J \propto v_d$.

That is, current density of a metallic conductor is directly proportional to the drift velocity.

Q. 3. Deduce Ohm's law using the concept of drift velocity.

OR

Define the term 'drift velocity' of charge carriers in a conductor. Obtain the expression for the current density in terms of relaxation time. **[*CBSE (F) 2014*]**

OR

Define relaxation time of the free electrons drifting in a conductor. How is it related to the drift velocity of free electrons? Use this relation to deduce the expression for the electrical resistivity of the material. **[*CBSE (AI) 2012*]**

OR

(*i*) On the basis of electron drift, derive an expression for resistivity of a conductor in terms of number density of free electrons and relaxation time. On what factors does resistivity of a conductor depend? **[*CBSE 2023 (55/2/1)*]**

(*ii*) Why alloys like constantan and manganin are used for making standard resistors? **[*CBSE Delhi 2016*]**

Ans. Relaxation time of free electrons drifting in a conductor is the average time elapsed between two successive collisions.

Deduction of Ohm's Law: Consider a conductor of length l and cross-sectional area A. When a potential difference V is applied across its ends, the current produced is I. If n is the number of electrons per unit volume in the conductor and v_d the drift velocity of electrons, then the relation between current and drift velocity is

$$I = -neAv_d \qquad \ldots(i)$$

where $-e$ is the charge on electron ($e = 1.6 \times 10^{-19}$ C)

Electric field produced at each point of wire, $E = \dfrac{V}{l}$ ...(*ii*)

If τ is relaxation time and E is electric field strength, then drift velocity

$$v_d = -\frac{e\tau E}{m} \qquad \ldots(iii)$$

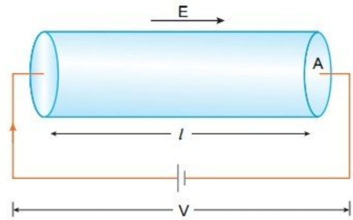
Substituting this value in (*i*), we get

$$I = -neA\left(-\frac{e\tau}{m}E\right) \quad \text{or} \quad I = \frac{ne^2\tau}{m}AE \qquad \ldots(iv)$$

As $E = \dfrac{V}{l}$ [From (*ii*)]

$$I=\frac{ne^2\tau A}{m}\frac{V}{l} \quad \text{or} \quad \frac{V}{I}=\frac{m}{ne^2\tau}\cdot\frac{l}{A} \qquad \ldots(v)$$

Current density $J\left(=\frac{I}{A}\right)=\frac{ne^2\tau}{ml}V.$



This is relation between current density J and applied potential difference V.

Under given physical conditions (temperature, pressure) for a given conductor

$$\frac{m}{ne^2\tau}\cdot\frac{l}{A}=\text{Constant}$$

$\therefore$ This constant is called the resistance of the conductor (*i.e.* R).

i.e., $$R=\frac{m}{ne^2\tau}\cdot\frac{l}{A} \qquad \ldots(vi)$$

From (v) and (vi); $\frac{V}{I}=R$ $\qquad \ldots(vii)$

This is Ohm's law. From equation (vi) it is clear that the resistance of a wire depends on its length (l), cross-sectional area (A), number of electrons per m^3 (n) and the relaxation time (τ)

Expression for resistivity:

As $$R=\frac{\rho l}{A} \qquad \ldots(viii)$$

Comparing (vi) and ($viii$), we get

Resistivity of a conductor $\rho=\frac{m}{ne^2\tau}$

Clearly, resistivity of a conductor is inversely proportional to number density of electrons and relaxation time.

Resistivity of the material of a conductor depends upon the relaxation time, *i.e.,* temperature and the number density of electrons.

This is because constantan and manganin show very weak dependence of resistivity on temperature.

Q. 4. Derive condition of balance of a Wheatstone bridge.

OR

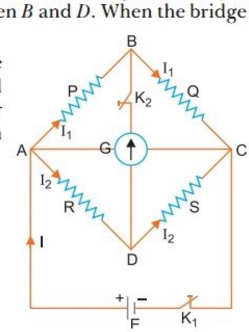
Draw a circuit diagram showing balancing of Wheatstone bridge. Use Kirchhoff's rules to obtain the balance condition in terms of the resistances of four arms of Wheatstone Bridge.

[*CBSE Delhi 2013, 2015*]

Ans. Condition of balance of a Wheatstone bridge:

The circuit diagram of Wheatstone bridge is shown in fig.

P, Q, R and S are four resistance forming a closed bridge, called Wheatstone bridge. A battery is connected across A and C, while a galvanometer is connected between B and D. When the bridge is balanced, there is no current in galvanometer.



Derivation of Formula: Let the current flowing in the circuit in the balanced condition be I. This current on reaching point A is divided into two parts I_1 and I_2. As there is no current in galvanometer in balanced condition, current in resistances P and Q is I_1 and in resistances R and S it is I_2.

Applying Kirchhoff's I law at point A,

$$I-I_1-I_2=0 \quad \text{or} \quad I=I_1+I_2 \qquad \ldots(i)$$

Applying Kirchhoff's II law to closed mesh $ABDA$,

$$-I_1P+I_2R=0 \quad \text{or} \quad I_1P=I_2R \qquad \ldots(ii)$$

Applying Kirchhoff's II law to mesh $BCDB$,

$$-I_1Q+I_2S=0 \quad \text{or} \quad I_1Q=I_2S \qquad \ldots(iii)$$

Dividing equation (*ii*) by (*iii*), we get

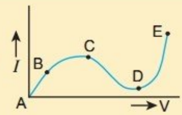
$$\frac{I_1 P}{I_1 Q} = \frac{I_2 R}{I_2 S} \quad \text{or} \quad \frac{P}{Q} = \frac{R}{S}$$

This is the ***condition of balance of Wheatstone bridge.***

Questions for Practice

1. Choose and write the correct option in the following questions.

(*i*) From the graph between current *I* and voltage *V* shown below, identify the portion corresponding to negative resistance



(*a*) *AB* (*b*) *BC* (*c*) *CD* (*d*) *DE*

(*ii*) The potential difference across a cell in an open circuit is 8 V. It falls to 4 V when a current of 4 A is drawn from it. The internal resistance of the cell is ***[CBSE 2023 (55/1/1)]***

(*a*) 4 Ω (*b*) 3 Ω (*c*) 2 Ω (*d*) 1 Ω

(*iii*) An electric current is passed through a circuit containing two wires of same material, connected in parallel. If the lengths and radii of the wires are in the ratio of 3:2 and 2:3, then the ratio of the current passing throught the wire will be

[CBSE Sample Paper 2022, Term-1]

(*a*) 2:3 (*b*) 3:2 (*c*) 8:27 (*d*) 27:8

(*iv*) Which one of the following is not a scalar quantity? ***[CBSE 2023 (55/3/1)]***

(*a*) Electric field (*b*) Voltage (*c*) Resistivity (*d*) Power

(*v*) $m^2V^{-1}s^{-1}$ is the SI unit of which of the following? ***[CBSE 2020 (55/3/1)]***

(*a*) Drift velocity (*b*) Mobility (*c*) Resistivity (*d*) Potential gradient

(*vi*) In a current carrying conductor, the ratio of the electric field and the current density at a point is called ***[CBSE 2020 (55/2/1)]***

(*a*) Resistivity (*b*) Conductivity (*c*) Resistance (*d*) Mobility

(*vii*) Ohm's law is obeyed by ***[CBSE 2020 (55/2/3)]***

(*a*) extrinsic semiconductors. (*b*) intrinsic semiconductors.

(*c*) metals at low temperature. (*d*) metals at high temperature.

(*viii*) The resistance of a metal wire increases with increasing temperature on account of

[CBSE 2020 (55/1/2)]

(*a*) decrease in free electron density. (*b*) decrease in relaxation time.

(*c*) increase in mean free path. (*d*) increase in the mass of electron.

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

(a) ***Both A and R are true and R is the correct explanation of A.***

(b) ***Both A and R are true but R is not the correct explanation of A.***

(c) ***A is true but R is false.***

(d) ***A is false and R is also false.***

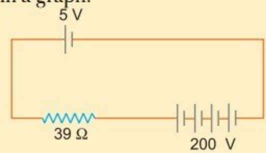
(*i*) **Assertion (*A*) :** The drift velocity of electrons in a metallic conductor decreases with rise of temperature of conductor.

Reason (*R*) : On increasing temperature, the collision of electrons with lattice ions increases; this hinders the drift of electrons.

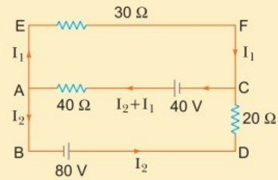
(*ii*) **Assertion (*A*) :** The resistance of a given mass of copper wire is inversely proportional to the square of length.

Reason (*R*) : When a copper wire of given mass is stretched to increase its length, its cross-sectional area also increases.

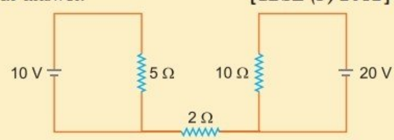
3. State the two Kirchhoff's rules used in electric networks. How are these rules justified?
4. Show variation of resistivity of copper as a function of temperature in a graph.
5. A 5 V battery of negligible internal resistance is connected across a 200 V battery and a resistance of 39 Ω as shown in the figure. Find the value of the current flowing in the circuit.



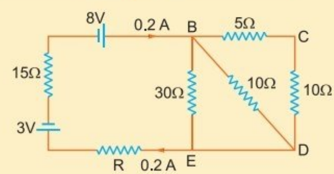
6. Two identical cells, each of emf E, having negligible internal resistance, are connected in parallel with each other across an external resistance R. What is the current through this resistance? **[*CBSE (AI) 2013*]**
7. Using Kirchhoff's rules, calculate the current in the arm AC of the given circuit.



8. A cell of emf 'E' and internal resistance 'r' is connected across a variable resistor 'R'. Plot a graph showing variation of terminal voltage 'V' of the cell versus the current 'I'. Using the plot, show how the emf of the cell and its internal resistance can be determined.
9. Estimate the average drift speed of conduction electrons in a copper wire of cross-sectional area 2.5×10^{-7} m^2 carrying a current of 1.8 A. Assume the density of conduction electrons to be 9×10^{28} m^{-3}.
10. A wire of 20 Ω resistance is gradually stretched to double its original length. It is then cut into two equal parts. These parts are then connected in parallel across a 4.0 volt battery. Find the current drawn from the battery.
11. A conductor of length 'l' is connected to a *dc* source of potential 'V'. If the length of the conductor is tripled by gradually stretching it, keeping 'V' constant, how will (*i*) drift speed of electrons and (*ii*) resistance of the conductor be affected? Justify your answer. **[*CBSE (F) 2012*]**
12. What will be the value of current through the 2 Ω resistance for the circuit shown in the figure? Give reason to support your answer. **[*CBSE (F) 2013*] [*HOTS*]**

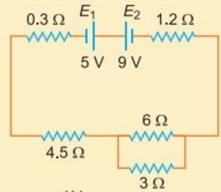


13. Calculate the value of the resistance R in the circuit shown in the figure so that the current in the circuit is 0.2 A. What would be the potential difference between points B and E? **[*CBSE (AI) 2012*] [*HOTS*]**



14. The storage battery of a car has an emf of 12 V. If the internal resistance of the battery is 0.4 Ω, what is the maximum current that can be drawn from the battery? **[*NCERT*]**
15. A battery of emf 10 V and internal resistance 3 Ω is connected to a resistor. If the current in the circuit is 0.5 A, what is the resistance of the resistor? What is the terminal voltage of the battery when the circuit is closed. **[*NCERT*]**
16. A negligibly small current is passed through a wire of length 15 m and uniform cross-section 6.0×10^{-7} m^2 and its resistance is measured to be 5.0 Ω. What is the resistivity of the material at the temperature of the experiment? **[*NCERT*]**
17. A silver wire has a resistance 2.1 Ω at 27.5°C and a resistance of 2.7 Ω at 100°C. Determine the temperature coefficient of the resistivity of silver.

18. Two cells E_1 and E_2 of emf's 5 V and 9 V and internal resistances of 0.3 Ω and 1.2 Ω respectively are connected to a network of resistances as shown in the figure. Calculate the value of current flowing through the 3 Ω resistance.



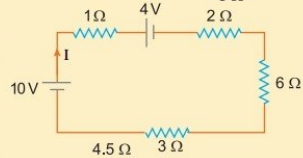
19. (*i*) Derive an expression for drift velocity of free electrons.

(*ii*) How does drift velocity of electrons in a metallic conductor vary with increase in temperature? Explain.

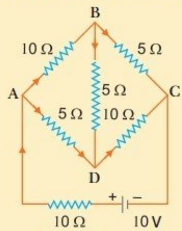
20. (*i*) High current is to be drawn safely from (1) a low-voltage battery, and (2) a high-voltage battery. What can you say about the internal resistance of the two batteries?

(*ii*) Calculate the energy supplied by the batteries to the circuit shown in the figure, in one minute.

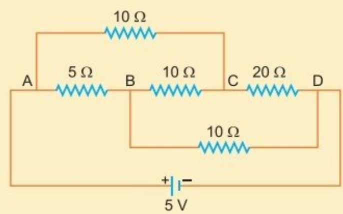
[*CBSE 2023 (55/4/1)*]



21. Determine the current in each branch of the network shown in figure.

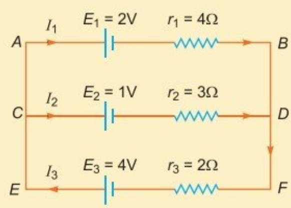


22. Calculate the value of the current drawn from a 5 V battery in the circuit as shown. **[*CBSE (F) 2013*]**



23. State Kirchhoff's rules. Use these rules to write the expressions for the currents I_1, I_2 and I_3 in the circuit diagram shown.

[*CBSE (AI) 2010*]



Answers

1. (*i*) (*c*) (*ii*) (*d*) (*iii*) (*c*) (*iv*) (*a*) (*v*) (*b*) (*vi*) (*a*) (*vii*) (*c*) (*viii*) (*b*) **2.** (*i*) (*a*) (*ii*) (*d*) **5.** 5 A **6.** $\frac{\varepsilon}{R}$ **7.** $\frac{22}{13}$ A

9. 5×10^{-4} **10.** 0.2 A **12.** 0A **13.** 1V **14.** 30 A **15.** 17Ω, 8.5V

16. 2×10^{-7}Ωm **17.** 0.0039/°C **18.** $\frac{1}{3}$ A **20.** (*ii*) 180J

21. $\frac{4}{7}$A, $\frac{6}{17}$A, $\frac{6}{17}$A, $\frac{4}{17}$A, $\frac{2}{17}$A, $\frac{10}{17}$A **22.** 0.5 A **23.** $I_1 = \frac{2}{13}$A, $I_2 = \frac{7}{13}$A, $I_3 = \frac{9}{13}$A,

4 Moving Charges and Magnetism

POINTS TO REMEMBER

1. **Magnetic Effect of Current**

   A magnetic field is associated with an electric current flowing through a metallic wire. This is called magnetic effect of current. On the other hand, a stationary electron produces electric field only.

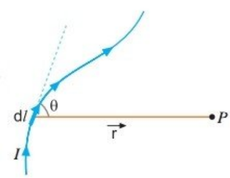
2. **Source and Units of Magnetic Field**

   Oersted's Experiment: A Danish physicist, Hans Christian Oersted, in 1820, demonstrated that a magnetic needle is deflected by a current carrying wire. He concluded that the magnetic field is caused by current elements (or moving charges). The unit of magnetic field strength in SI system is tesla (T) or weber/metre^2 (Wb m^{-2}) or newton/ampere-metre (N A^{-1} m^{-1}).

   In CGS system, the unit of magnetic field is gauss (G).

   $$1\text{T} = 10^4\text{ G}$$

3. **Biot-Savart Law**

   It states that the magnetic field strength $\overrightarrow{dB}$ produced due to a current element (of current I and length dl) at a point having position vector $\vec{r}$ relative to current element is

   $$\overrightarrow{dB} = \frac{\mu_0}{4\pi}\frac{I\overrightarrow{dl} \times \vec{r}}{r^3}$$

   where μ_0 is permeability of free space. Its value is

   $\mu_0 = 4\pi \times 10^{-7}$ Wb/A-m.

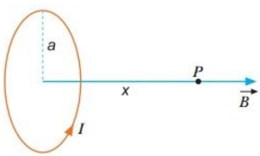
   The magnitude of magnetic field is

   $$dB = \frac{\mu_0}{4\pi}\frac{Idl\sin\theta}{r^2}$$

   where θ is the angle between current element Idl and position vector $\vec{r}$ as shown in the figure.

   The direction of magnetic field $\overrightarrow{dB}$ is perpendicular to the plane containing $I\overrightarrow{dl}$ and $\vec{r}$.

4. **Magnetic Field due to a Circular Coil**

   The magnetic field due to current carrying circular coil of N-turns, radius a, carrying current I at a distance x from the centre of coil is

   $$B = \frac{\mu_0 NIa^2}{2(a^2 + x^2)^{3/2}} \text{ along the axis.}$$

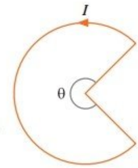
   At centre, $x = 0$

   $$\therefore \quad B_c = \frac{\mu_0 NI}{2a}$$

The direction of magnetic field at the centre is perpendicular to the plane of the coil.

In general the field produced by a circular arc subtending an angle θ at centre is

$$B_C = \frac{\mu_0 I}{2a} \cdot \frac{\theta}{2\pi} \qquad (\theta \text{ in radian})$$



5. Ampere's Circuital Law

It states that the line integral of magnetic field $\vec{B}$ along a closed path is equal to μ_0-times the current (I) passing through the closed path.

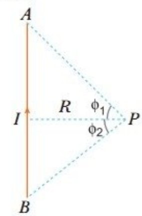
$$\oint \vec{B} \cdot \vec{dl} = \mu_0 I$$

6. Magnetic Field due to a Straight Conductor Carrying a Current using

Biot-Savart Law

The magnetic field due to a straight current carrying wire of finite length at a point is

$$B = \frac{\mu_0 I}{4\pi R}(\sin\phi_1 + \sin\phi_2)$$



where R is the perpendicular distance of the point from the conductor.

The direction of magnetic field is given by right hand grip rule.

Special cases: (*i*) If the wire is infinitely long, then $\phi_1 = \pi/2$, $\phi_2 = \pi/2$

$$B = \frac{\mu_0 I}{2\pi R}$$

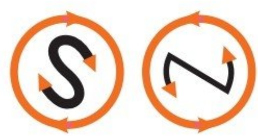
(*ii*) If point is near one end of a long wire, $(\phi_1 = \frac{\pi}{2}, \phi_2 = 0)$, then

$$B = \frac{\mu_0 I}{4\pi R}$$

7. Magnetic Field due to a Current Carrying Solenoid

At the axis of a long solenoid, carrying a current I

$$B = \mu_0 n I$$



where n = number of turns per unit length.

Magnetic field at one end of solenoid $B_{end} = \frac{\mu_0 n I}{2}$

The polarity of any end is determined by using Ampere's right hand rule.

8. Force on a Moving Charged Particle in Magnetic Field

The force on a charged particle moving with velocity $\vec{v}$ in a uniform magnetic field $\vec{B}$ is given by

$$\vec{F}_m = q(\vec{v} \times \vec{B}) = qvB\sin\theta$$

This is known as Lorentz force.

The direction of this force is determined by using Fleming's left hand rule.

The direction of this force is perpendicular to both $\vec{v}$ and $\vec{B}$,

When $\vec{v}$ is parallel to $\vec{B}$, then $\vec{F}_m = 0$

When $\vec{v}$ is perpendicular to $\vec{B}$, then $\vec{F}_m$ is maximum, *i.e.*, $F_m = qvB$.

9. Force on a Charged Particle in Simultaneous Electric and Magnetic Fields

The **total force** on a charged particle moving in simultaneous electric field $\vec{E}$ and magnetic field $\vec{B}$ is given by

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

This is called **Lorentz force equation**.

10. Path of Charged Particle in a Uniform Magnetic Field

(*i*) If $\vec{v}$ is parallel to the direction of $\vec{B}$, then magnetic force = zero. So the path of particle is an undeflected straight line.

(*ii*) If $\vec{v}$ is perpendicular to $\vec{B}$, then magnetic field provides a force whose direction is perpendicular to both $\vec{v}$ and $\vec{B}$ and the particle follows a circular path. The radius r of path is given by

$$\frac{mv^2}{r} = qvB \Rightarrow r = \frac{mv}{qB}$$

If K is kinetic energy of a particle, then $P = mv = \sqrt{2mK}$

$$r = \frac{\sqrt{2mK}}{qB}$$

If V is accelerating potential in volt, $K = qV$

$$\therefore \qquad r = \frac{\sqrt{2mqV}}{qB} = \frac{1}{B}\sqrt{\frac{2mV}{q}}$$

Time period of revolution is $T = \dfrac{2\pi\, m}{qB}$

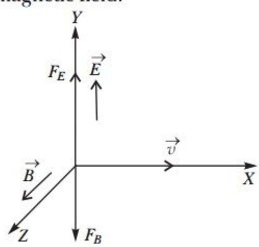
(*iii*) If a particle's velocity $\vec{v}$ is oblique to magnetic field $\vec{B}$, then the particle follows a **helical path** of radius, $r = \dfrac{mv\sin\theta}{qB} = \dfrac{mv_{\perp}}{qB}$

Time period, $T = \dfrac{2\pi m}{qB}$

and pitch, $P = v_{||}T = v\cos\theta\dfrac{2\pi m}{qB}$

where $v_{||}$ is a component of velocity parallel to the direction of magnetic field.

11. Velocity Filter

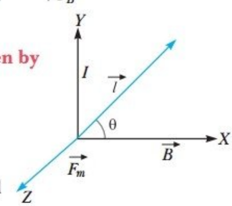


If electric and magnetic fields are mutually perpendicular and a charged particle enters this region with velocity $\vec{v}$ which is perpendicular to both electric and magnetic fields, then it may happen that the electric and magnetic forces are equal and opposite and charged particle with given velocity v remain undeflected in both fields. In such a condition

$$qE = qvB \Rightarrow v = \frac{E}{B}$$

This arrangement is called velocity filter or velocity selector.

12. Magnetic Force on a Current Carrying Conductor of Length $\vec{l}$ is given by



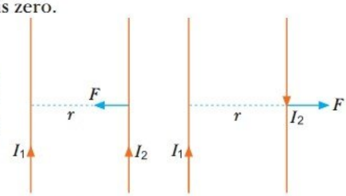
$$\vec{F}_m = I(\vec{l}\times\vec{B})$$

Magnitude of force is

$$F_m = IlB\sin\theta$$

Direction of force $\vec{F}$ is normal to $\vec{l}$ and $\vec{B}$ given by Fleming's Left Hand Rule. If $\theta = 0$ (*i.e.*, $\vec{l}$ is parallel to $\vec{B}$), then magnetic force is zero.

13. Force between Parallel Current Carrying Conductors



Two parallel current carrying conductors attract while antiparallel current carrying conductors repel. The magnetic force per unit length on either current carrying conductor at separation 'r' is given by

$$\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r} \text{newton/metre}$$

$$= 2 \times 10^{-7} \frac{I_1 I_2}{r}$$

Its unit is newton/metre abbreviated as N/m.

- **Definition of ampere in SI System**

  1 ampere is the current which when flowing in each of the two parallel wires in vacuum at separation of 1 m from each other exert a force of

  $$\frac{\mu_0}{2\pi} = 2 \times 10^{-7} \text{N/m on each other.}$$

14. Torque Experienced by a Current Loop (of Area $\vec{A}$) Carrying Current I in a Uniform Magnetic Field $\vec{B}$ is given by

$$\vec{\tau} = NI(\vec{A} \times \vec{B}) = \vec{M} \times \vec{B}$$

where $\vec{M} = NI\vec{A}$ is magnetic moment of loop. The unit of magnetic moment in SI system is ampere × metre^2 (Am^2).

15. Potential energy of a current loop in a magnetic field

When a current loop of magnetic moment M is placed in a magnetic field, then potential energy of magnetic dipole is

$$U = -\vec{M}.\vec{B} = -MB\cos\theta$$

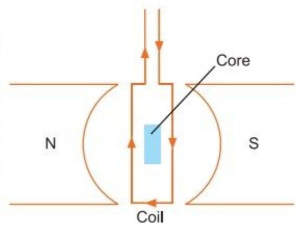
(*i*) When $\theta = 0$, $U = -MB$ (minimum or stable equilibrium position)

(*ii*) When $\theta = \pi$, $U = +MB$ (maximum or unstable equilibrium position)

(*iii*) When $\theta = \frac{\pi}{2}$, $U = 0$.

16. Moving Coil Galvanometer

A moving coil galvanometer is a device used to detect flow of current in a circuit.



A moving coil galvanometer consists of a rectangular coil placed in a uniform radial magnetic field produced by cylindrical pole pieces. Torque on coil $\tau = NIAB$ where N is number of turns, A is area of coil. If C is torsional rigidity of material of suspension wire, then for deflection θ, torque $\tau = C\theta$

$\therefore$ For equilibrium, $NIAB = C\theta$

$$\Rightarrow \quad \theta = \frac{NAB}{C} I \quad \Rightarrow \theta \propto I$$

Clearly, deflection in galvanometer is directly proportional to current, so the scale of galvanometer is linear.

Figure of Merit of a galvanometer: The current which produces a deflection of one scale division in the galvanometer is called its figure of Merit. It is equal to $\frac{I}{\theta} = \frac{C}{NAB}$

Sensitivity of a galvanometer: Current sensitivity: It is defined as the deflection of coil per unit current flowing in it.

Sensitivity $S_I = \left(\frac{\theta}{I}\right) = \frac{NAB}{C}$

Voltage sensitivity: It is defined as the deflection of coil per unit potential difference across its ends

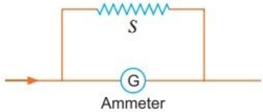
i.e., $S_V = \frac{\theta}{V} = \frac{NAB}{R_g . C}$

where R_g is resistance of galvanometer.

Clearly for greater sensitivity, number of turns N, area A and magnetic field strength B should be large and torsional rigidity C of suspension should be small.

17. Conversion of Galvanometer into Ammeter

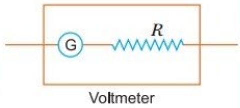
A galvanometer may be converted into ammeter by using very small resistance in parallel with the galvanometer coil. The small resistance connected in parallel is called a **shunt**. If G is resistance of galvanometer, I_g is current in galvanometer for full scale deflection, then for conversion of galvanometer into ammeter of range I ampere, the shunt is given by



$$S = \frac{I_g}{I - I_g} G$$

18. Conversion of Galvanometer into Voltmeter

A galvanometer may be converted into voltmeter by connecting high resistance (R) in series with the coil of galvanometer. If V volt is the range of voltmeter formed, then series resistance is given by



$$R = \frac{V}{I_g} - G$$

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Multiple Choice Questions

Choose and write the correct option(s) in the following questions.

1. If a conducting wire carries a direct current through it, the magnetic field associated with the current will be __________ .

(*a*) both inside and outside the conductor (*b*) neither inside nor outside the conductor
(*c*) only outside the conductor (*d*) only inside the conductor

2. A region has a uniform magnetic field in it. A proton enters into the region with velocity making an angle of 45° with the direction of the magnetic field. In this region the proton will move on a path having the shape of a **[*CBSE 2020 (55/3/1)*]**

(*a*) straight line (*b*) circle (*c*) spiral (*d*) helix

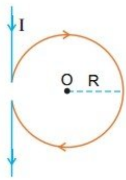
3. Two charged particles traverse identical helical paths in a completely opposite sense in a uniform magnetic field $B = B_0 \hat{k}$. **[*NCERT Exemplar*]**

(*a*) They have equal z-components of momenta

(*b*) They must have equal charges

(*c*) They necessarily represent a particle, anti-particle pair

(*d*) The charge to mass ratio satisfy: $\left(\frac{e}{m}\right)_1 + \left(\frac{e}{m}\right)_2 = 0$



4. A current *I* flows through a long straight conductor which is bent into circular loop of radius *R* in the middle as shown in the figure.
The magnitude of the net magnetic field at point *O* will be [*CBSE 2020 (55/4/1)*]

(*a*) zero (*b*) $\frac{\mu_0 I}{2R}(1+\pi)$ (*c*) $\frac{\mu_0 I}{4\pi R}$ (*d*) $\frac{\mu_0 I}{2R}\left(1 - \frac{1}{\pi}\right)$

5. Biot-Savart law indicates that the moving electrons (velocity v) produce a magnetic field B such that [*NCERT Exemplar*]

(*a*) B is perpendicular to v

(*b*) B is parallel to v

(*c*) it obeys inverse cube law

(*d*) it is along the line joining the electron and point of observation

6. An electron is projected with uniform velocity along the axis of a current carrying long solenoid. Which of the following is true? [*NCERT Exemplar*]

(*a*) The electron will be accelerated along the axis

(*b*) The electron path will be circular about the axis

(*c*) The electron will experience a force at 45° to the axis and hence execute a helical path

(*d*) The electron will continue to move with uniform velocity along the axis of the solenoid

7. A micro-ammeter has a resistance of 100 Ω and a full scale range of 50 m μA. It can be used as a higher range ammeter or voltmeter provided resistance is added to it. Pick the correct range and resistance combinations.

(*a*) 50 V range and 10 kΩ resistance in series

(*b*) 10 V range and 200 kΩ resistance in series

(*c*) 5 mA range with 1 Ω resistance in parallel

(*d*) 10 mA range with 1 Ω resistance in parallel.

8. A current carrying circular loop of radius R is placed in the x-y plane with centre at the origin. Half of the loop with $x > 0$ is now bent so that it now lies in the y-z plane. [*NCERT Exemplar*]

(*a*) The magnitude of magnetic moment now diminishes.

(*b*) The magnetic moment does not change.

(*c*) The magnitude of B at $(0,0, z)$, $z>>R$ increases.

(*d*) The magnitude of B at $(0,0, z)$, $z>>R$ is unchanged.

9. The sensitivity of a moving coil galvanometer increases with the decrease in

(*a*) number of turns (*b*) area of coil

(*c*) magnetic field (*d*) torsional rigidity

10. A voltmeter of range 2V and resistance 300 Ω cannot be converted to an ammeter of range

(*a*) 5 mA (*b*) 8 mA (*c*) 1 A (*d*) 10 A

11. In an ammeter 4% of the mains current is passing through galvanometer. If the galvanometer is shunted with a 5 Ω resistance, then resistance of galvanometer will be

(*a*) 116 Ω (*b*) 117 Ω (*c*) 118 Ω (*d*) 120 Ω

12. A rectangular coil of length 0.12 m and width 0.1 m having 50 turns of wire is suspended vertically in a uniform magnetic field of strength 0.2 Weber/m^2. The coil carries a current of 2 A. If the plane of the coil is inclined at an angle of 30° with the direction of the field, the torque required to keep the coil in stable equilibrium will be

(*a*) 0.24 Nm (*b*) 0.12 Nm (*c*) 0.15 Nm (*d*) 0.20 Nm

13. An electron is released from rest in a region of uniform electric and magnetic fields acting parallel to each other. The electron will [*CBSE 2020 (55/2/1)*]

(*a*) move in a straight line. (*b*) move in a circle.

(*c*) remain stationary. (*d*) move in a helical path.

14. A straight current carrying conductor is placed inside a uniform magnetic field. The force per unit length acting on the conductor is [*CBSE 2020 (55/2/3)*]

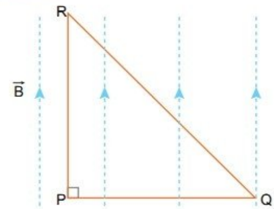
(*a*) maximum when the conductor is perpendicular to the direction of magnetic field.

(*b*) maximum when the conductor is along the direction of magnetic field.

(*c*) minimum when the conductor is perpendicular to the direction of magnetic field.

(*d*) minimum when the conductor makes an angle of 45° with the direction of magnetic field.

15. **An isosceles right angled current carrying loop PQR is placed in a uniform magnetic field $\vec{B}$ pointing along PR. If the magnetic force acting on the arm PQ is F, then the magnetic force which acts on the arm QR will be** [*CBSE 2020 (55/3/1)*]



(*a*) F (*b*) $\frac{F}{\sqrt{2}}$ (*c*) $\sqrt{2}F$ (*d*) $-F$

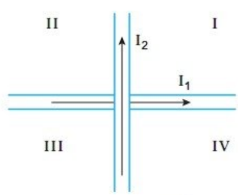
16. **A current of 10 A is flowing from east to west in a long straight wire kept on a horizontal table. The magnetic field developed at a distance of 10 cm due north on the table is:** [*CBSE 2020 (55/4/1)*]

(*a*) 2×10^{-5} T, acting downwards (*b*) 2×10^{-5} T, acting upwards
(*c*) 4×10^{-5} T, acting downwards (*d*) 4×10^{-5} T, acting upwards

17. **An electron and a proton are moving along the same direction with the same kinetic energy. They enter a uniform magnetic field acting perpendicular to their velocities. The dependence of radius of their paths on their masses is:** [*CBSE 2020 (55/4/2)*]

(*a*) $r \propto m$ (*b*) $r \propto \sqrt{m}$ (*c*) $r \propto \frac{1}{m}$ (*d*) $r \propto \frac{1}{\sqrt{m}}$

18. **Two wires carrying currents I_1 and I_2 lie, one slightly above the other, in a horizontal plane as shown in figure. The region of vertically upward strongest magnetic field is** [*CBSE 2022 (55/2/4), Term-1*]



(*a*) I (*b*) II (*c*) III (*d*) IV

19. **The magnetic field at the centre of a current carrying circular loop of radius R, is B_1. The magnetic field at a point on its axis at a distance R from the centre of the loop is B_2. Then the ratio (B_1/B_2) is** [*CBSE 2022 (55/2/4), Term-1*]

(*a*) $2\sqrt{2}$ (*b*) $\frac{1}{\sqrt{2}}$ (*c*) $\sqrt{2}$ (*d*) 2

20. **A current carrying wire kept in a uniform magnetic field, will experience a maximum force when it is** [*CBSE 2022 (55/2/4), Term-1*]

(*a*) perpendicular to the magnetic field (*b*) parallel to the magnetic field
(*c*) at an angle of 45° to the magnetic field (*d*) at an angle of 60° to the magnetic field

21. **If an ammeter is to be used in place of a voltmeter, then we must connect with the ammeter a** [*CBSE 2022 (55/2/4), Term-1*]

(*a*) low resistance in parallel (*b*) low resistance in series
(*c*) high resistance in parallel (*d*) high resistance in series

22. **A straight conducting rod of length l and mass m is suspended in a horizontal plane by a pair of flexible strings in a magnetic field of magnitude B. To remove the tension in the supporting strings, the magnitude of the current in the wire is** [*CBSE 2022 (55/2/4), Term-1*]

(*a*) $\frac{mgB}{l}$ (*b*) $\frac{mgl}{B}$ (*c*) $\frac{mg}{lB}$ (*d*) $\frac{lB}{mg}$

23. **Which of the following statements is correct?** [*CBSE 2022 (55/2/4), Term-1*]

(*a*) Magnetic field lines do not form closed loops.

(*b*) Magnetic field lines start from north pole and end at south pole of a magnet.

(*c*) The tangent at a point on a magnetic field line represents the direction of the magnetic field at that point.

(*d*) Two magnetic field lines may intersect each other.

24. **A proton and an alpha particle move in circular orbits in a uniform magnetic field. Their speeds are in the ratio of 9 : 4. The ratio of radii of their circular orbits $\left(\frac{r_p}{r_{alpha}}\right)$ is** [*CBSE Sample paper-2022, Term-1*]

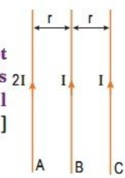
(*a*) $\frac{3}{4}$ (*b*) $\frac{4}{3}$ (*c*) $\frac{8}{9}$ (*d*) $\frac{9}{8}$

25. **The current sensitivity of a galvanometer increases by 20%. If its resistance also increases by 25%, the voltage sensitivity will** [*CBSE Sample Paper-2022, Term-1*]

(*a*) decrease by 1% (*b*) increase by 5%

(*c*) increase by 10% (*d*) decrease by 4%

26. **Three infinitely long parallel straight current carrying wires A, B and C are kept at equal distance from each other as shown in the figure . The wire C experiences net force F .The net force on wire C, when the current in wire A is reversed will be** [*CBSE Sample Paper-2022, Term-1*]



(*a*) zero (*b*) $F/2$

(*c*) F (*d*) $2F$

27. **Beams of electrons and protons move parallel to each other in the same direction. They** [*CBSE 2023 (55/2/1)*]

(*a*) attract each other.

(*b*) repel each other.

(*c*) neither attract nor repel.

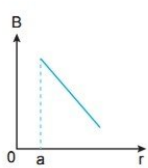
(*d*) force of attraction or repulsion depends upon speed of beams.

28. **A long stratight wire of radius 'a' carries a steady current 'I'. The current is uniformly distributed across its area of cross-section. The ratio of magnitude of magnetic field $\overrightarrow{B_1}$ at $\frac{a}{2}$ and $\overrightarrow{B_2}$ at distance $2a$ is** [*CBSE 2023 (55/2/1)*]

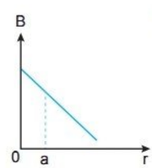
(*a*) $\frac{1}{2}$ (*b*) 1 (*c*) 2 (*d*) 4

29. **Which of the following graphs correctly represents the variation of the magnitude of the magnetic field outside a straight infinite current carrying wire of radius 'a', as a function of distance 'r' from the centre of the wire?** [*CBSE 2023 (55/3/1)*]

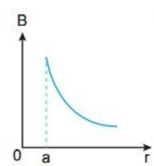
(*a*)



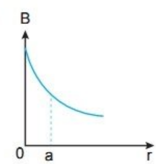
(*b*)



(*c*)



(*d*)



30. An electron enters a uniform magnetic field with speed v. It describes a semicircular path and comes out of the field. The final speed of the electron is **[*CBSE 2023 (55/4/1)*]**

(*a*) zero (*b*) v (*c*) $\frac{v}{2}$ (*d*) $2v$

Answers

1. (*c*)	**2.** (*d*)	**3.** (*d*)	**4.** (*d*)	**5.** (*a*)	**6.** (*d*)	**7.** (*b,c*)
8. (*a*)	**9.** (*d*)	**10.** (*a*)	**11.** (*d*)	**12.** (*d*)	**13.** (*a*)	**14.** (*a*)
15. (*d*)	**16.** (*a*)	**17.** (*b*)	**18.** (*b*)	**19.** (*a*)	**20.** (*a*)	**21.** (*d*)
22. (*c*)	**23.** (*c*)	**24.** (*d*)	**25.** (*d*)	**26.** (*a*)	**27.** (*b*)	**28.** (*b*)
29. (*c*)	**30.** (*b*)					

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(*a*) ***Both A and R are true and R is the correct explanation of A.***

(*b*) ***Both A and R are true but R is not the correct explanation of A.***

(*c*) ***A is true but R is false.***

(*d*) ***A is false and R is also false.***

1. Assertion (*A*) : On increasing the current sensitivity of a galvanometer by increasing the number of turns, may not necessarily increase its voltage sensitivity.

Reason (*R*) : The resistance of the coil of the galvanometer increases on increasing the number of turns. **[*CBSE Sample Paper-2022, Term-1*]**

2. Assertion (*A*) : When a magnetic dipole is placed in a non uniform magnetic field, only a torque acts on the dipole.

Reason (*R*) : Force would not act on dipole if magnetic field were non uniform.

3. Assertion (*A*) : To increase the range of an ammeter, we must connect a suitable high resistance in series to it.

Reason (*R*) : The ammeter with increased range should have high resistance.

[*CBSE Sample Paper-2022, Term-1*]

4. Assertion (*A*) : Galvanometer cannot as such be used as an ammeter to measure the value of the current in a given circuit.

Reason (*R*) : It gives a full-scale deflection for a current of the order of micro ampere.

5. Assertion (*A*) : Higher the range, lower is the resistance of an ammeter.

Reason (*R*) : To increase the range of an ammeter additional shunt is added in series to it.

[*CBSE 2022 (55/2/4), Term-1*]

6. Assertion (*A*) : A proton and an electron, with same momenta, enter in a magnetic field in a direction at right angles to the lines of the force. The radius of the paths followed by them will be same.

Reason (*R*) : Electron has less mass than the proton. **[*CBSE Sample Paper-2022, Term-1*]**

7. Assertion (*A*) : Magnetic field is caused by current element.

Reason (*R*) : Magnetic field due to a current element $I\,\vec{dl}$ is $\vec{dB} = \frac{\mu_0}{4\pi}\frac{I\vec{dl}\times\vec{r}}{r^3}$

8. **Assertion (A)** : If a proton and an α-particle enter a uniform magnetic field perpendicularly with the same speed, the time period of revolution of α-particle is double that of proton.

Reason (R) : In a magnetic field, the period of revolution of a charged particle is directly proportional to the mass of the particle and is inversely proportional to charge of particle. *[AIIMS 2010]*

9. **Assertion (A)** : When radius of a circular loop carrying a steady current is doubled, its magnetic moment becomes four times.

Reason (R) : The magnetic moment of a circular loop carrying a steady current is proportional to the area of the loop. *[CBSE 2023 (55/3/1)]*

10. **Assertion (A)** : A current carrying square loop made of a wire of length L is placed in a magnetic field. It experiences a torque which is greater than the torque on a circular loop made of the same wire carrying the same current in the same magnetic field.

Reason (R) : A square loop occupies more area than a circular loop, both made of wire of the same length. *[CBSE 2023 (55/4/1)]*

Answers

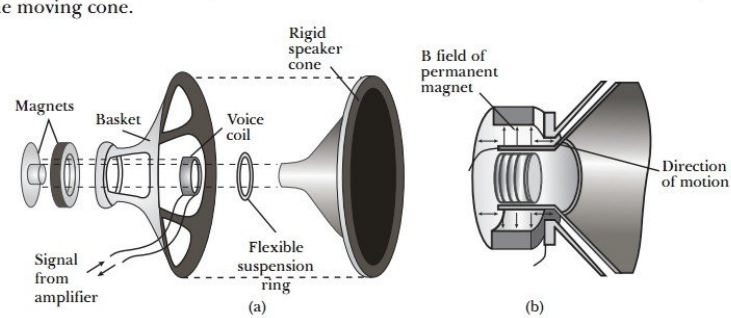
1. (a) **2.** (d) **3.** (d) **4.** (a) **5.** (c) **6.** (b) **7.** (b)
8. (a) **9.** (a) **10.** (b)

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Case-based/Passage-based Questions

Read the paragraph given below and answer the questions that follow:

Loudspeakers: A common application of the magnetic force on a current carrying wire is found in loudspeakers. The magnetic field created by the permanent magnet exerts a force on the voice coil that is proportional to the current in the coil; the direction of the force is either to the left or to the right, depending on the direction of the current. The signal coming from the amplifier causes the current to oscillate in direction and magnitude. The coil and the speaker cone to which it is attached respond by oscillating with an amplitude proportional to the amplitude of the current in the coil. Turning up the volume knob on the amplifier increases the current amplitude and hence the amplitudes of the cone's oscillation and of the sound wave produced by the moving cone.



The force is always perpendicular to both the conductor and the field, with the direction determined by the same right-hand rule we used for a moving positive charge. Hence, this force can be expressed as a vector product, just like the force on a single moving charge. We represent the segment of wire with a vector $\vec{l}$ along the wire in the direction of the current, then force $\vec{F}$ on this segment is

$$\vec{F} = I\vec{l} \times \vec{B} \text{ (i.e., magnetic force on a straight wire segment)}$$

(*i*) Loudspeaker works on the principle of

(*a*) detector (*b*) generator (*c*) amplifier (*d*) motor

(*ii*) Electrodynamic speaker can handle which type of audio power relative to permanent magnet type speaker?

(*a*) Lower (*b*) Equal

(*c*) Higher (*d*) Both (*a*) and (*b*)

(*iii*) To increase the power handling capacity in loudspeakers which type of magnet is used?

(*a*) Temporary magnet (*b*) Permanent magnet

(*c*) Electromagnet (*d*) None of these

OR

A horizontal wire 0.1 m long carries a current of 5 A. Find the magnitude and direction of the magnetic field, which can balance the weight of wire. Given the mass of the wire is 3×10^{-3} kg/m and $g = 10$ m/s^2.

(*a*) 6×10^{-3} T, acting horizontally perpendicular to wire

(*b*) 6×10^{-3} T, acting vertically upwards

(*c*) 6×10^{-2} T, acting vertically downwards

(*d*) 6×10^{-2} T, acting horizontally perpendicular to wire

(*iv*) A square current carrying loop is suspended in a uniform magnetic field acting in the plane of the loop. If the force on one arm of the loop is $\vec{F}$, the net force on the remaining three arms of the loop is

(*a*) $\vec{F}$ (*b*) $-\vec{F}$ (*c*) $3\vec{F}$ (*d*) $-3\vec{F}$

Explanations

(*i*) (*d*) A common application of the magnetic force on a current carrying wire is found in loudspeakers as similar case in motor in which current carrying coil experience force in presence of magnetic field.

(*ii*) (*c*) It is a type of higher audio power relative to permanent magnet type speaker.

(*iii*) (*c*) The electromagnet is used to increase the power handling capacity in loudspeakers.

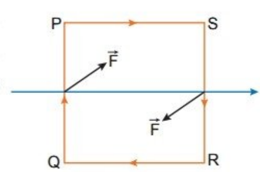
OR

(*a*) In equilibrium position, $F = IlB = mg$

$$\Rightarrow \qquad B = \frac{mg}{Il} = \frac{(0.1 \times 3 \times 10^{-3}) \times 10}{5 \times 0.1} = 6 \times 10^{-3}\text{ T}$$

The weight is wire be supported by force F if it acts vertically upwards. It will be so if the direction of $\vec{B}$ is horizontal and perpendicular to wire carrying current.

(*iv*) (*b*) As clear from figure, force on arm PS and arm RQ is zero. If $\vec{F}$ is force on arm RS, the force on arm PQ is $-\vec{F}$. Therefore, net force on the remaining three arms of the loop $= -\vec{F}$.



CONCEPTUAL QUESTIONS

Q. 1. Write the expression, in a vector form, for the Lorentz magnetic force $\vec{F}$ due to a charge moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$. What is the direction of the magnetic force? **[*CBSE Delhi 2014*]**

Ans. Force, $\vec{F} = q(\vec{v} \times \vec{B})$

Obviously, the force on charged particle is perpendicular to both velocity $\vec{v}$ and magnetic field $\vec{B}$.

Q. 2. When a charged particle moving with velocity $\vec{v}$ is subjected to magnetic field $\vec{B}$, the force acting on it is non-zero. Would the particle gain any energy? **[*CBSE (F) 2013*]**

Ans. No. (*i*) This is because the charge particle moves on a circular path.

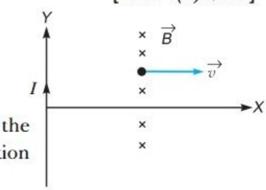
(*ii*) $\vec{F} = q(\vec{v} \times \vec{B})$

and power dissipated $P = \vec{F} \cdot \vec{v}$ $\quad [\because \vec{v} \times \vec{B} \perp \vec{v}]$

$$= q(\vec{v} \times \vec{B}).\vec{v} = 0$$

The particle does not gain any energy.

Q. 3. A long straight wire carries a steady current *I* along the positive *Y*-axis in a coordinate system. A particle of charge +*Q* is moving with a velocity $\vec{v}$ along the *X*-axis. In which direction will the particle experience a force? **[*CBSE (F) 2013*]**



Ans. From relation $\vec{F} = qvB[\hat{i} \times (-\hat{k})] = +qvB(\hat{j})$

Magnetic force $\vec{F}$ along + *Y* axis.

OR

From Fleming's left hand rule, thumb points along +*Y* direction, so the direction of magnetic force will be along + *Y* axis (or in the direction of flow of current).

Q. 4. What can be the cause of helical motion of a charged particle? **[*CBSE North 2016*]**

Ans. Charge particle moves inclined to the magnetic field. When there is an angle between velocity of charged particle and magnetic field, then the vertical component of velocity ($v \sin \theta$) will rotate the charge particle on circular path, but horizontal component ($v \cos \theta$) will move the charged particle in straight line. Hence path of the charge particle becomes helical.

Q. 5. In a certain region of space, electric field $\vec{E}$ and magnetic field $\vec{B}$ are perpendicular to each other. An electron enters in the region perpendicular to the directions of both $\vec{B}$ and $\vec{E}$ and moves undeflected. Find the velocity of the electron. **[*HOTS*] [*CBSE (F) 2013*]**

Ans. Net force on electron moving in the combined electric field $\vec{E}$ and magnetic field $\vec{B}$ is

$$\vec{F} = -e[\vec{E} + \vec{v} \times \vec{B}]$$

Since electron moves undeflected then $\vec{F} = 0$.

$$\vec{E} + \vec{v} \times \vec{B} = 0$$

$$\Rightarrow \quad |\vec{E}| = |\vec{v} \times \vec{B}| \quad \Rightarrow \quad |\vec{v}| = \frac{|\vec{E}|}{|\vec{B}|}$$

Q. 6. A narrow beam of protons and deuterons, each having the same momentum, enters a region of uniform magnetic field directed perpendicular to their direction of momentum. What would be the ratio of the circular paths described by them? **[*CBSE (F) 2011*]**

OR

A proton and a deuteron having equal momenta enter in a region of uniform magnetic field at right angle to the direction of the field. Find the ratio of the radii of curvature of the path of the particle. **[*CBSE Delhi 2013*]**

Ans. Charge on deutron (q_d) = charge on proton (q_p)

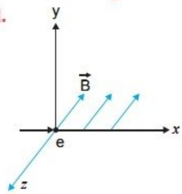
Radius of circular path $(r) = \dfrac{P}{Bq} \quad \left(\because qvB = \dfrac{mv^2}{r}\right)$

$$r \propto \frac{1}{q} \quad \text{[for constant momentum } (P)]$$

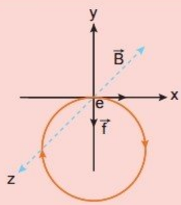
So, $$\frac{r_p}{r_d} = \frac{q_d}{q_p} = \frac{q_p}{q_p} = 1$$

Hence, $r_p : r_d = \mathbf{1 : 1}$

Q. 7. An electron moves along +*x* direction. It enters into a region of uniform magnetic field $\vec{B}$ directed along –*z* direction as shown in fig. Draw the shape of trajectory followed by the electron after entering the field. *[CBSE 2020 (55/5/1)]*



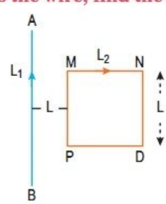
Ans.



Alternatively: Circular path in the *X-Y* plane in clockwise sense. ½ + ½

Note: If the student just writes, force on the electron will be along negative *Y* axis, *i.e.*, $F = -e(v\hat{i}) \times (B(-\hat{k}) = evB(-\hat{j})$ award ½ mark only *[CBSE Marking Scheme 2020 (55/5/1)]*

Q. 8. A square shaped current carrying loop *MNOP* is placed near a straight long current carrying wire *AB* as shown in the figure. The wire and the loop lie in the same plane. If the loop experiences a net force F towards the wire, find the magnitude of the force on the side 'NO' of the loop. *[CBSE 2020 (55/5/1)]*



Ans. Magnitude of force on side NO is $= F$

Alternatively

Let force on side *MP* be $= F_1$

Force on side $NO = F$ ½

Magnitude of net force $= F_1 - \dfrac{F_1}{2} = \dfrac{F_1}{2} = F$ ½

Therefore force on side $NO = \dfrac{F_1}{2} = F$ *[CBSE Marking Scheme 2020 (55/5/1)]*

Q. 9. A square coil of side 10 cm consists of 20 turns and carries a current of 12 A. The coil is suspended vertically and normal to the plane of the coil makes an angle of 30° with the direction of uniform horizontal magnetic field of magnitude 0.80 T. What is the magnitude of the torque experienced by the coil? **[*NCERT*]**

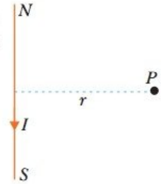
Ans. Torque on coil $\tau = NIAB \sin \theta$

Here $N = 20; A = 10 \text{ cm} \times 10 \text{ cm} = 100 \text{ cm}^2 = 100 \times 10^{-4} \text{ m}^2$

$I = 12 \text{ A}, \theta = 30°, \ B = 0.80 \text{ T}$

$\therefore \quad \tau = (20) \times (12) \times (100 \times 10^{-4}) \times 0.80 \sin 30° = 24 \times 0.8 \times \left(\frac{1}{2}\right) \times 10^{-1} = \mathbf{0.96 \text{ Nm}}$

Q. 10. A long straight wire in the horizontal plane carries a current of 50 A in north to south direction. Give the magnitude and direction of B at a point 2.5 m east of the wire?

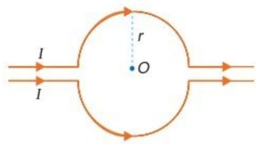


Ans. Given $I = 50$ A, $r = 2.5$ m

$$B = \frac{\mu_0 I}{2\pi r} = \frac{4\pi \times 10^{-7} \times 50}{2\pi \times 2.5} = \mathbf{4 \times 10^{-6} \text{ T}}$$

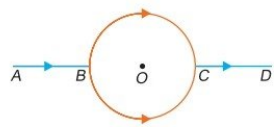
By right hand palm rule the magnetic field is directed vertically upward.

Q. 11. What is the value of magnetic field at point *O* due to current flowing in the wires as shown in figure? **[*HOTS*]**



Ans. Zero, because the upper and lower current carrying conductors are identical and so the magnetic fields caused by them at the centre *O* will be equal and opposite.

Q. 12. What is the magnetic field at point *O* due to current carrying wires shown in figure? **[*HOTS*]**



Ans. The magnetic field due to straight wires *AB* and *CD* is zero since either $\theta = 0°$ or $180°$ and that due to a semi-circular arc are equal and opposite; hence net field at *O* is zero.

Q. 13. What is the magnitude of magnetic force per unit length on a wire carrying a current of 8 A and making an angle of 30° with the direction of a uniform magnetic field of 0.15 T? **[*NCERT*]**

Ans. Magnetic force, $F = BIl \sin \theta$

Magnetic force per unit length,

$$f = \frac{F}{l} = BI \sin \theta = 0.15 \times 8 \times \sin 30° = \mathbf{0.6 \text{ N/m}}$$

Q. 14. A proton and an electron travelling along parallel paths enter a reion of uniform magnetic field, acting perpendicular to their paths. Which of them will move in a circular path with higher frequency? **[*CBSE 2018*]**

Ans. Electron

Reason: When the charge particle enters perpendicular to the magnetic field it traces circular path.

$$\frac{mv^2}{r} = q\,vB \qquad \Rightarrow \qquad r = \frac{mv}{qB}$$

$$\Rightarrow \qquad r = \frac{m(\omega r)}{qB} \qquad (\because v = \omega r)$$

$$\Rightarrow \qquad \omega = \frac{qB}{m} \qquad \Rightarrow \qquad 2\pi \upsilon = \frac{qB}{m}$$

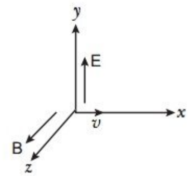
$$\Rightarrow \qquad \upsilon = \frac{qB}{2\pi m} \qquad \Rightarrow \qquad \upsilon \propto \frac{q}{m}$$

Since, electron has less mass, so it will move with high frequency.

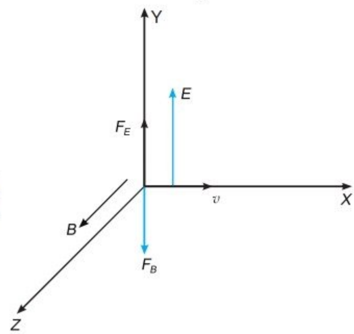
Very Short Answer Questions

Each of the following questions are of 2 marks.

Q. 1. A particle of charge q is moving with velocity v in the presence of crossed Electric field E and Magnetic field B as shown. Write the condition under which the particle will continue moving along x-axis. How would the trajectory of the particle be affected if the electric field is switched off? *[CBSE Sample Paper 2018]*



Ans. Consider a charge q moving with velocity v in the presence of electric and magnetic fields. The force on an electric charge q due to both of them is



$$\vec{F} = q\left[\vec{E}(r) + \vec{v} \times \vec{B}(r)\right]$$

where, v = velocity of the charge

r = location of the charge at a given time t

$E(r)$ = Electric field

$B(r)$ = Magnetic field

Let us consider a simple case in which electric and magnetic fields are perpendicular to each other and also perpendicular to the velocity of the particle.

$$\vec{F}_E = q\vec{E} = qE\,\hat{j}$$

$$\vec{F}_B = q\vec{v}\times\vec{B} = q(v\,\hat{i}\times B\,\hat{k}) = -qvB\,\hat{j}$$

$$\therefore \qquad \vec{F} = q(E - vB)\,\hat{j}$$

Thus, electric and magnetic forces are in opposite directions.

Suppose we adjust the values of E and B such that magnitudes of the two forces are equal, then the total force on the charge is zero and the charge will move in the fields undeflected. This happens when

$$qE = qvB \qquad \text{or} \quad v = \frac{E}{B}$$

This condition can be used to select charged particles of a particular velocity out of a beam containing charges moving with different speeds (irrespective of their charge and mass). The crossed E and B fields therefore serve as a velocity selector.

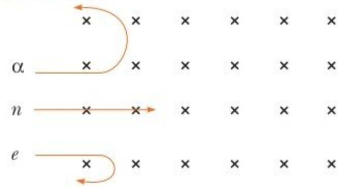
Trajectory becomes helical about the direction of magnetic field.

Q. 2. (*i*) Write the expression for the magnetic force acting on a charged particle moving with velocity v in the presence of magnetic field B.

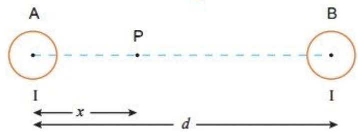
(*ii*) A neutron, an electron and an alpha particle moving with equal velocities, enter a uniform magnetic field going into the plane of the paper as shown. Trace their paths in the field and justify your answer. *[CBSE Delhi 2016]*

Ans. (*i*) $\vec{F} = q(\vec{v} \times \vec{B})$

(*ii*) Force on alpha particle and electron are opposite to each other, magnitude of mass per charge ratio of alpha particle is more than electron (*i.e.*, $r \propto \frac{m}{q}$) hence radius of alpha particle is more than radius of electron.



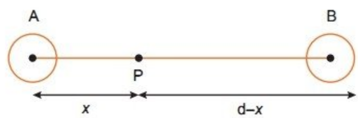
Q. 3. Two long straight parallel wires *A* and *B* separated by a distance *d*, carry equal current *I* flowing in same direction as shown in the figure.



(*a*) Find the magnetic field at a point *P* situated between them at a distance *x* from one wire.
(*b*) Show graphically the variation of the magnetic field with distance *x* for $0 < x < d$.

[*CBSE 2020 (55/1/1)*]

Ans. (*a*)



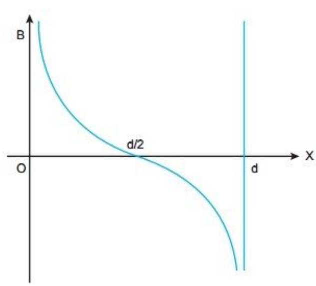
Magnetic field at *P* due to long straight wire, $B = \dfrac{\mu_0 I}{2\pi x}$

$$\overrightarrow{B_P} = \overrightarrow{B_A} + \overrightarrow{B_B} = \frac{\mu_0 I}{2\pi x}(\text{upwards}) + \frac{\mu_0 I}{2\pi(d-x)}(\text{downwards})$$

$$= \frac{\mu_0 I}{2\pi}\left(\frac{1}{x} - \frac{1}{d-x}\right)$$

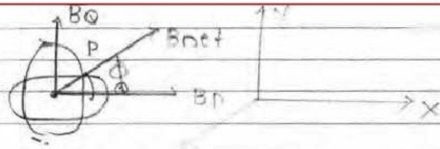
$$= \frac{\mu_0 I}{2\pi}\left(\frac{d-x-x}{x(d-x)}\right) = \frac{\mu_0 I}{2\pi}\,\frac{(d-2x)}{x(d-x)} \text{ upwards as } B_A > B_B$$

(*b*)



Q. 4. Two identical circular coils, P and Q each of radius R, carrying currents 1 A and $\sqrt{3}$ A respectively, are placed concentrically and perpendicular to each other lying in the XY and YZ planes. Find the magnitude and direction of the net magnetic field at the centre of the coils. **[*CBSE (AI) 2017*]**

Ans.



The magnetic field due to the coil P at the centre

$$B_P = \frac{\mu_0 I}{2R} = \frac{\mu_0}{2R}$$

$$B_Q = \frac{\mu_0 I}{2R} = \frac{\mu_0 \times \sqrt{3}}{2R} = \frac{\sqrt{3}\mu_0}{2R}$$

$$B_{net} = \sqrt{B_1^2 + B_2^2} = \sqrt{\frac{\mu_0^2}{4R^2} + \frac{3\mu_0^2}{4R^2}} = \sqrt{\frac{4\mu_0^2}{4R^2}} = \frac{2\mu_0}{2R} = \frac{\mu_0}{R}$$

The direction is along B_{net} making ~~45°~~ 60° with the Bp.

$$\tan\phi = \frac{B_Q}{B_P} = \frac{\sqrt{3}\mu_0}{2R} \times \frac{2R}{\mu_0} = \sqrt{3}$$

in the plane of the two coils

$$\phi = 60^\circ$$

[*Topper's Answer 2017*]

Q. 5. An electron is revolving around the nucleus in a circular orbit with a speed of 10^7 m s^{-1}, If the radius of the orbit is 10^{-10}m, find the current constituted by the revolving electron in the orbit. **[*CBSE 2023 (55/1/1)*]**

Ans. Here, $v = 10^7$ ms^{-1}, $r = 10^{-10}$ m

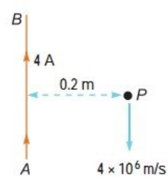
Time period of electron to revolve in orbit, $T = \dfrac{2\pi r}{v}$

Now, current, $I = \dfrac{e}{T} = \dfrac{e}{\frac{2\pi r}{v}} = \dfrac{ev}{2\pi r} = \dfrac{1.6\times10^{-19}\times10^{7}}{2\times3.14\times10^{-10}} = \dfrac{16\times100}{628\times10}\times10^{-2}$

$= 2.54 \times 10^{-3}$ A

$=$ **2.54 mA**

Q. 6. A long straight wire AB carries a current of 4 A. A proton P travels at 4×10^6 ms^{-1} parallel to the wire 0.2 m from it and in a direction opposite to the current as shown in the figure. Calculate the force which the magnetic field due to the current carrying wire exerts on the proton. Also specify its direction. **[*CBSE 2019 (55/4/1)*]**



Ans. Given, $I = 4$ A, $r = 0.2$ m, $v = 4\times10^6$ m/s

Magnetic field at Point P due current carrying straight wire AB

$$B = \frac{\mu_0}{2\pi}\frac{I}{r}$$

Force acting on the moving proton in the magnetic field

$$F = Bqv\ \text{Sin}\theta$$

Therefore, $$F = \frac{\mu_\circ}{2\pi}\frac{I}{r} \times qv \sin\theta$$

$$= \frac{2\times10^{-7}\times4\times1.6\times10^{-19}\times4\times10^{6}\sin 90}{0.2}$$

$$= \mathbf{2.56 \times 10^{-18}\ N}$$

Direction of force at point P is towards right. (away from AB)

Q. 7. An alpha particle is projected with velocity $\vec{v} = (3.0 \times 10^5\ \text{m/s})\ \hat{i}$ into a region in which magnetic field $\vec{B} = [(0.4\ \text{T})\ \hat{i} + (0.3\ \text{T})\ \hat{j}\ ]$ exists. Calculate the acceleration of the particle in the region. $\hat{i}$, $\hat{j}$ and $\hat{k}$ are unit vectors along x, y and z axis respectively and charge to mass ratio for alpha particle is 4.8×10^7 C/kg. *[CBSE 2023 (55/1/1)]*

Ans. Here, $\vec{v} = 3 \times 10^5$ m/s $\hat{i}$, $\vec{B} = 0.4\ \hat{i} + 0.3\ \hat{j}$ T.

Charge to mass ratio, $\frac{q}{m} = 4.8 \times 10^7$ C/kg [For α-particle]

From Lorentz's force,

$$\vec{F} = q(\vec{v} \times \vec{B})$$

$$= q(3\times10^5\hat{i})\times(0.4\hat{i} + 0.3\hat{j})$$

$$= q\left(1.2\times10^5(\hat{i}\times\hat{i}) + 0.9\times10^5(\hat{i}\times\hat{j})\right)$$

$$= q(0.9\times10^5\hat{k}) \qquad [\hat{i}\times\hat{i}=0]$$

Now, $$a = \frac{\vec{F}}{m} = \frac{q}{m}(0.9\times10^5)\hat{k}$$

$$= 4.8\times10^7\times0.9\times10^5\ \hat{k}$$

$$= \mathbf{4.32\times10^{12}\ m/s^2\ \hat{k}}.$$

Q. 8. A wire of length l is in the form of a circular loop A of one turn. This loop is reshaped into loop B of three turns. Find the ratio of the magnetic fields at the centres of loop A and loop B for the same current through them. *[CBSE 2023 (55/3/1)]*

Ans. For circular loop A, $N = 1$, $n = 3$

$$B_A = \frac{\mu_0 I}{2r}$$

For circular loop B, $N = 3$, $I' = I$

As form given, $3\times2\pi r' = L$

$$6\pi r' = L$$

$\therefore$ $$r' = \frac{L}{6\pi} = \frac{1}{3}\left(\frac{L}{2\pi}\right) = \frac{r}{3} \qquad \left[\begin{array}{l}\because 2\pi r = L\\ \therefore r = \dfrac{L}{2\pi}\end{array}\right]$$

Now, $$B_B = \frac{\mu_0 N I'}{2r'} = \frac{\mu_0 3I}{2\left(\frac{r}{3}\right)} = \frac{9\mu_0 I}{2r}$$

Hence, ratio, $$\frac{B_A}{B_B} = \frac{\frac{\mu_0 I}{2r}}{\frac{9\mu_0 I}{2r}} = \mathbf{\frac{1}{9}}$$

Q. 9. A deuteron and an alpha particle having same momentum are in turn allowed to pass through a magnetic field $\vec{B}$, acting normal to the direction of motion of the particles. Calculate the ratio of the radii of the circular paths described by them. [*CBSE 2019* (*55/1/2*)]

Ans.

7. Mass of deuteron = 2u (m_D)
Mass of alpha particle = 4u (m_α)
Charge on deuteron = +e (q_D)
Charge on α particle = +2e (q_α) $\left(\because \frac{mv^2}{r} = qvB\right)$

Radius of path of deuteron, $r_D = \frac{m_D v_D}{q_D B} = \frac{p_D}{q_D B}$

Radius of path of α-particle, $r_\alpha = \frac{m_\alpha v_\alpha}{q_\alpha B} = \frac{p_\alpha}{q_\alpha B}$

So, $\frac{r_D}{r_\alpha} = \frac{p_D}{p_\alpha} \frac{q_\alpha}{q_D} = \frac{2e}{e} = 2$

(as both have same momentum)

So, $r_D : r_\alpha = 2 : 1 = \frac{2}{1}$
(deuteron : α-particle)

[*Topper's Answer 2019*]

Q. 10. State two reasons why a galvanometer can not be used as such to measure current in a given circuit. [*CBSE Delhi 2010*]

OR

Can a galvanometer as such be used for measuring the current? Explain.

Ans. A galvanometer cannot be used as such to measure current due to following two reasons.

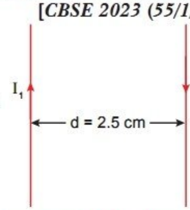
(*i*) A galvanometer has a finite large resistance and is connected in series in the circuit, so it will increase the resistance of circuit and hence change the value of current in the circuit.

(*ii*) A galvanometer is a very sensitive device, it gives a full scale deflection for the current of the order of microampere, hence if connected as such it will not measure current of the order of ampere.

Q. 11. Two long parallel straight wires *A* and *B* are 2.5 cm apart in air. They carry 5.0 A and 2.5 A currents respectively in opposite directions. Calculate the magnitude of the force exerted by wire *A* on a 10 cm length of wire *B*. [*CBSE 2023* (*55/1/1*)]

Ans. Here, $d = 2.5 \text{ cm} = 2.5 \times 10^{-2} \text{ m}, I_1 = 5\text{A}, I_2 = 2.5 \text{ A}$

$l = 10 \text{ cm} = 10 \times 10^{-2} \text{ m}.$



When tin current flow in opposite direction, then they repel each other by magnetic force,

$$F = \frac{\mu_0 I_1 I_2 l}{2\pi d} = \frac{4\pi \times 10^{-7} \times 5 \times 2.5 \times 10 \times 10^{-2}}{2\pi \times 2.5 \times 10^{-2}} = \mathbf{10^{-5} N}.$$

Q. 12. A closely wound solenoid 80 cm long has 5 layers of windings of 400 turns each. The diameter of the solenoid is 1.8 cm. If the current carried is 8.0 A, estimate the magnitude of $\vec{B}$ inside the solenoid near its centre. [*NCERT*]

Ans. Given $I = 80 \text{ cm} = 0.80 \text{ m}, N = 5 \times 400 = 2000, I = 8.0 \text{ A}$

Magnetic field inside the solenoid,

$$B = \mu_0 n I = \frac{\mu_0 N I}{l} = \frac{4\pi \times 10^{-7} \times 2000 \times 8.0}{0.80}$$

$$= 8\pi \times 10^{-3} \text{ T} = \mathbf{2.5 \times 10^{-2} \text{ T}}$$

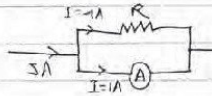
Q. 13. An ammeter of resistance 0.8 Ω can measure a current up to 1.0 A. Find the value of shunt resistance required to convert this ammeter to measure a current up to 5.0A. *[CBSE 2020 (55/2/1)]*

Ans. 2

Let the shunt resistance be of R Ω and it is connected in parallel with ammeter of resistance 0.8 Ω.

In the converted ammeter, 5 A current can enter.

∵ ammeter can take upto 1A, remaining 4A flows through shunt.



∵ R and ammeter are in parallel,

$4R = 1 \times 0.8$ 1

$\Rightarrow R = \frac{0.8}{4} = 0.2\ \Omega$.

∴ value of shunt $= 0.2\ \Omega$ (Ans) 1

[Topper's Answer 2020]

Short Answer Questions

Each of the following questions are of 3 marks.

Q. 1. Write any two important points of similarities and differences each between Coulomb's law for the electrostatic field and Biot-Savart's law for the magnetic field. *[CBSE (F) 2015]*

Ans. Similarities:

Both electrostatic field and magnetic field:

(*i*) follows the principle of superposition.

(*ii*) depends inversely on the square of distance from source to the point of interest.

Differences:

(*i*) Electrostatic field is produced by a scalar source (q) and the magnetic field is produced by a vector source $(I\vec{dl})$.

(*ii*) Electrostatic field is along the displacement vector between source and point of interest; while magnetic field is perpendicular to the plane, containing the displacement vector and vector source.

(*iii*) Electrostatic field is angle independent, while magnetic field is angle dependent between source vector and displacement vector.

Q. 2. A proton, a deuteron and an alpha particle, are accelerated through the same potential difference and then subjected to a uniform magnetic field $\vec{B}$, perpendicular to the direction of their motions. Compare (*i*) their kinetic energies, and (*ii*) if the radius of the circular path described by proton is 5 cm, determine the radii of the paths described by deuteron and alpha particle. *[CBSE 2019 (55/4/1)]*

Ans. (*i*) Since $qV = \frac{1}{2}mv^2$

For proton, $\frac{1}{2}m_p v_1^2 = qV$

For deuteron, $\frac{1}{2}m_d v_2^2 = qV$

For alpha particle $\frac{1}{2}m_\alpha v_3^2 = 2qV$

$(K.E.)_p : (K.E.)_d : (K.E.)_\alpha = \mathbf{1 : 1 : 2}$

(*ii*) We have, $Bqv = \frac{mv^2}{r}$ So, $r_p = \frac{mv}{Bq} = 5$ cm;

$$r_p : r_d : r_\alpha = v_p : v_d : v_\alpha = 1 : \sqrt{2} : \sqrt{2}$$

$$\therefore \quad \mathbf{r_d = 5\sqrt{2}\,cm, \quad r_\alpha = 5\sqrt{2}\,cm}$$

Q. 3. **(*a*) A circular coil of 30 turns and radius 8.0 cm carrying a current of 6.0 A is suspended vertically in a uniform horizontal magnetic field of magnitude 1.0 T. The field lines make an angle of 60° with the normal of the coil. Calculate the magnitude of counter-torque that must be applied to prevent the coil from turning.**

(*b*) Would your answer change, if the circular coil in (*a*) were replaced by a planar coil of some irregular shape that encloses the same area?

(All other particulars are also unaltered). **[*NCERT*]**

Ans. (*a*) Given $N = 30, A = \pi r^2 = \pi \times (8.0 \times 10^{-2})^2\ \text{m}^2$

$$I = 6.0\ A, B = 1.0\ \text{T}, \theta = 60°$$

Torque $\tau = NIAB \sin\theta$

$$= 30 \times 6.0 \times \pi \times (8.0 \times 10^{-2})^2 \times 1.0 \times \sin 60°$$

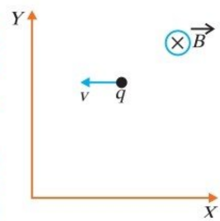
$$= 30 \times 6.0 \times 3.14 \times 64 \times 10^{-4} \times \left(\frac{\sqrt{3}}{2}\right) = \mathbf{3.13\ Nm}$$

(*b*) As the expression for torque contains only area not the shape of coil, so torque on a planar loop will remain the same provided magnitude of area is same.

Q. 4. **(*i*) A point charge q moving with speed v enters a uniform magnetic field B that is acting into the plane of the paper as shown. What is the path followed by the charge q and in which plane does it move?**

(*ii*) How does the path followed by the charge get affected if its velocity has a component parallel to $\vec{B}$?

(*iii*) If an electric field $\vec{E}$ is also applied such that the particle continues moving along the original straight line path, what should be the magnitude and direction of the electric field $\vec{E}$? **[*CBSE (F) 2016*]**



Ans. (*i*) The force experienced by the charge particle is given by $\vec{F} = q(\vec{v} \times \vec{B})$ when $\vec{v}$ is perpendicular to $\vec{B}$, the force on the charge particle acts as the centripetal force and makes it move along a circular path. Path followed by charge is anticlockwise in *X-Y* plane. The point charge moves in the plane perpendicular to both $\vec{v}$ and $\vec{B}$.

(*ii*) A component of velocity of charge particle is parallel to the direction of the magnetic field, the force experienced due to that component will be zero. This is because $F = qvB \sin 0° = 0$. Thus, particle will move in straight line.

Also, the force experienced by the component perpendicular to $\vec{B}$ moves the particle in a circular path. The combined effect of both the components will move the particle in a helical path.

(*iii*) Magnetic force on the charge, q

$$\vec{F}_B = q(\vec{v} \times \vec{B}) = q(v(-\hat{i}) \times B(-\hat{k})) = qvB(-\hat{j})$$

Hence, for moving charge, q in its original path

$$\vec{F}_E + \vec{F}_B = 0$$

$$\vec{F}_E = qvB(\hat{j}) \qquad \therefore \quad \vec{E} = vB(\hat{j})$$

Taking magnitude both sides

$$|\vec{E}| = q\frac{vB}{q} = vB$$

Direction of Lorentz magnetic force is (–ve) y-axis. Therefore, direction of $\vec{E}$ is along (+ve) y-axis.

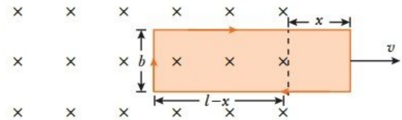
Q. 5. A rectangular loop which was initially inside the region of uniform and time - independent magnetic field, is pulled out with constant velocity v as shown in the figure.

(a) Sketch the variation of magnetic flux, the induced current, and power dissipated as Joule heat as function of time.

(b) If instead of rectangular loop, circular loop is pulled out; do you expect the same value of induced current? Sketch the variation of flux in this case with time. Justify your answer.

[*CBSE Sample Paper 2021*]

Ans. (*a*) We know that



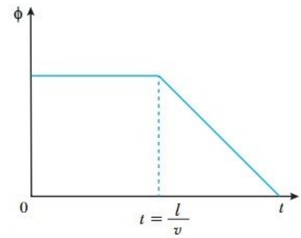
$$\phi = \vec{B}\,.\,\vec{A} \;= Blb = \text{constant}$$

at t, $\quad \phi = \vec{B}.\vec{A} \;= B(l-x)b$

$$\phi = Bb(l-vt) = Bbl - Bvbt$$

$$\phi = \begin{cases} Blb & t=0 \\ Blb - Bbvt & t=t \end{cases}$$

Now, $\quad \varepsilon = -\dfrac{d\phi}{dt} = \dfrac{d}{dt}(Blb - Bvbt)$



$$\varepsilon = Bvb$$

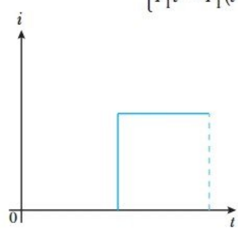
$$i = \frac{\varepsilon}{R} = \frac{Bvb}{R}$$

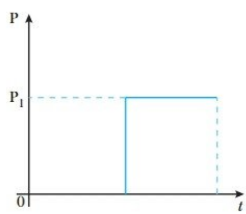
$$\varepsilon = \begin{cases} 0 \Rightarrow i = 0 \text{ at } t=0 \\ Bvb \Rightarrow i = \dfrac{Bvb}{R} = \text{constant } at\ t \end{cases}$$

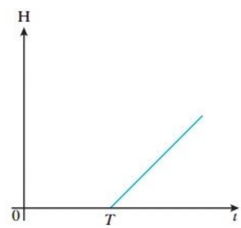
$$P = VI$$

$$P = \begin{cases} 0 \text{ at } t=0 \\ (Bvb)\left(\dfrac{Bvb}{R}\right) = P_1 \text{ (let) at } t \end{cases}$$

$$H = Pt = \begin{cases} 0 \ \text{ at } t=0 \\ P_1 t = P_1(t-T) \text{ at } t \end{cases}$$

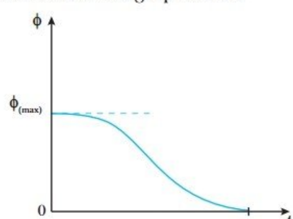






(*b*) When a circular loop is pulled out of a region of uniform magnetic field, the rate of change of area is not constant and hence the induced current varies accordingly.

The variation of flux is shown in the graph below.



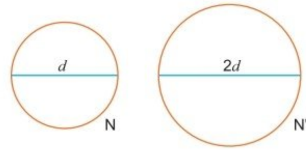
Q. 6. A circular coil of '*N*' turns and diameter '*d*' carries a current '*I*'. It is unwound and rewound to make another coil of diameter '*2d*', current '*I*' remaining the same. Calculate the ratio of the magnetic moments of the new coil and the original coil. **[*CBSE (AI) 2012*]**

Ans. We know,

magnetic moment (m) = NIA

where N = Number of turns

Then, length of wire remains same



Thus, $N \times \left[2\pi\left(\frac{d}{2}\right)\right] = N'\left[2\pi\left(\frac{2d}{2}\right)\right] \Rightarrow N' = \frac{N}{2}$

Now, $m_A = NIA_A = NI(\pi r_A^2) = \frac{1}{4}NI\pi d^2$

Similarly, $m_B = N'I\,A_B = \frac{NI}{2}(\pi r_B^2) = \frac{1}{2}(NI\pi d^2)$

$$\frac{m_B}{m_A} = \frac{\frac{1}{2}}{\frac{1}{4}} = \frac{2}{1} \Rightarrow \frac{m_B}{m_A} = \mathbf{\frac{2}{1}}$$

Q. 7. An α-particle and a proton of the same kinetic energy are in turn allowed to pass through a magnetic field $\vec{B}$, acting normal to the direction of motion of the particles. Calculate the ratio of radii of the circular paths described by them. **[*CBSE 2019 (55/5/3)*]**

Ans. The radius of circular path is given by

$$r = \frac{mv}{qB}$$

Let m_p and v_p are the mass of proton and velocity. Also m_α and v_α is the mass and velocity of α-particle.

According to question

$$\frac{1}{2}m_p v_p^2 = K \qquad ...(i)$$

Also, $$\frac{1}{2}m_\alpha {v^2}_\alpha = K \qquad ...(ii)$$

From equation (i), we have

$$m_p {v^2}_p = 2K$$

Momentum of proton $= m_p v_p = \sqrt{m_p 2K}$

Now, $$r_p = \frac{\sqrt{2m_p K}}{qB}$$

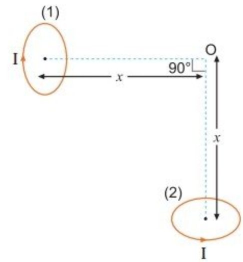
Similarly, $$r_\alpha = \frac{\sqrt{2m_\alpha K}}{q_\alpha \beta} \qquad [\because q_\alpha = 2q_p]$$

Now, $$\frac{r_\alpha}{r_p} = \frac{\sqrt{2m_\alpha K}}{2q_p B} \times \frac{qpB}{\sqrt{2m_p K}} \qquad [\because m_\alpha = 4m_p]$$

$$= \frac{1}{2}\sqrt{\frac{m_\alpha}{m_p}} = \frac{1}{2}\sqrt{\frac{4m_p}{m_p}} = \frac{1}{2} \times 2 = 1:1$$

$\therefore \quad r_\alpha : r_p = \mathbf{1:1}$

Q. 8. Two small identical circular loops, marked (1) and (2), carrying equal currents, are placed with the geometrical axes perpendicular to each other as shown in the figure. Find the magnitude and direction of the net magnetic field produced at the point *O*.
[*CBSE (F) 2013, 2014*]

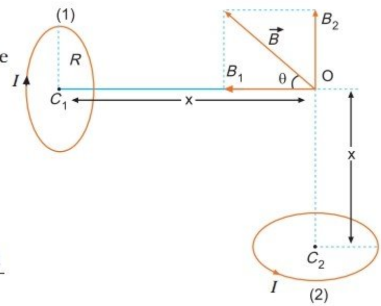


Ans. Magnetic field due to coil 1 at point O,

$$\vec{B}_1 = \frac{\mu_0 I R^2}{2(R^2+x^2)^{3/2}} \text{ along } \overrightarrow{OC_1}$$

Magnetic field due to coil 2 at point O,

$$\vec{B}_2 = \frac{\mu_0 I R^2}{2(R^2+x^2)^{3/2}} \text{ along } \overrightarrow{C_2O}$$



Both $\vec{B}_1$ and $\vec{B}_2$ are mutually perpendicular, so the net magnetic field at O is

$$B = \sqrt{B_1^2 + B_2^2} = \sqrt{2}\,B_1 \text{ (as } B_1 = B_2)$$

$$= \sqrt{2}\frac{\mu_0 I R^2}{2(R^2+x^2)^{3/2}}$$

As $R << x$,

$$B = \frac{\sqrt{2}\,\mu_0 I R^2}{2x^3} = \frac{\mu_0}{4\pi}\,\frac{2\sqrt{2}\,.\,I(\pi R^2)}{x^3} = \boldsymbol{\frac{\mu_0}{4\pi}\frac{2\sqrt{2}\,.\,IA}{x^3}}$$

where $A = \pi R^2$ is area of loop.

$$\tan\theta = \frac{B_2}{B_1} \Rightarrow \tan\theta = 1 \quad (\because B_2 = B_1) \Rightarrow \quad \theta = \boldsymbol{\frac{\pi}{4}}$$

$\therefore$ $\vec{B}$ is directed at an angle $\frac{\pi}{4}$ with the direction of magnetic field $\vec{B}_1$.

Q. 9. Two identical coils *P* and *Q* each of radius *R* are lying in perpendicular planes such that they have a common centre. Find the magnitude and direction of magnetic field at the common centre of the two coils, if they carry currents equal to *I* and $\sqrt{3}$ *I* respectively.
[*CBSE (F) 2016, 2019 (55/5/1)*] [*HOTS*]

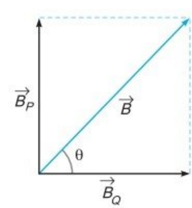
Ans. Given that two identical coils are lying in perpendicular planes and having common centre. P and Q carry current I and $\sqrt{3}\,I$ respectively.

Now, magnetic field at the centre of P due to its current I,

$$\vec{B}_P = \frac{\mu_0 I}{2R}$$

And, magnetic field at centre of Q due to its current $\sqrt{3}\,I$,

$$\vec{B}_Q = \frac{\mu_0\sqrt{3}\,I}{2R}$$



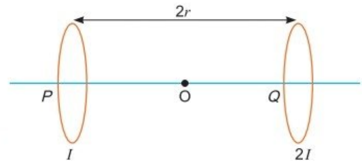
$$\therefore \qquad |B_{net}| = \sqrt{B_P^2 + B_Q^2}$$

$$= \sqrt{\left(\frac{\mu_0 I}{2R}\right)^2 + \left(\frac{\mu_0\sqrt{3}\,I}{2R}\right)^2} = \frac{\mu_0 I}{2R}\times 2 = \boldsymbol{\frac{\mu_0 I}{R}}$$

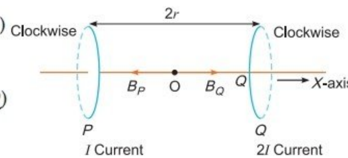
For direction,

$$\therefore \qquad \tan\theta = \frac{|\vec{B}_P|}{|\vec{B}_Q|} = \left(\frac{\dfrac{\mu_0 I}{2R}}{\dfrac{\mu_0\sqrt{3}\,I}{2R}}\right) = \frac{1}{\sqrt{3}} \quad \Rightarrow \quad \theta = \tan^{-1}\left(\frac{1}{\sqrt{3}}\right) = \mathbf{30°}$$

Q. 10. Two identical circular loops, P and Q, each of radius r and carrying currents I and $2I$ respectively are lying in parallel planes such that they have a common axis. The direction of current in both the loops is clockwise as seen from O which is equidistant from the both loops. Find the magnitude of the net magnetic field at point O. **[CBSE (Delhi) 2012] [HOTS]**



Ans. As we know,



$$|\vec{B}_P| = \frac{\mu_0 r^2 I}{2(r^2+r^2)^{3/2}} = \frac{\mu_0 I}{4\sqrt{2}r} \text{ (Pointing towards } P)$$

$$|\vec{B}_Q| = \frac{\mu_0 (2I) r^2}{2(r^2+r^2)^{3/2}} = \frac{\mu_0 2I}{4\sqrt{2}r} \text{ (Pointing towards } Q)$$

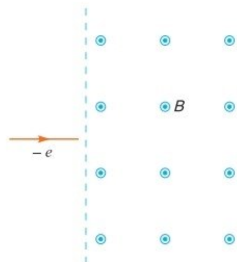
$$|\vec{B}| = |\vec{B}_Q| - |\vec{B}_P| = \boldsymbol{\frac{\mu_0 I}{4\sqrt{2}r}}$$

So, magnetic field at point O has a magnitude $\frac{\mu_0 I}{4\sqrt{2}r}$.

Q. 11. (a) An electron moving horizontally with a velocity of 4×10^4 m/s enters a region of uniform magnetic field of 10^{-5} T acting vertically upward as shown in the figure. Draw its trajectory and find out the time it takes to come out of the region of magnetic field.

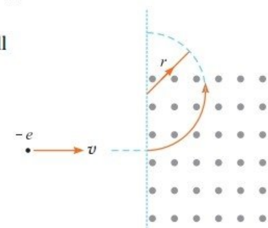
(b) A straight wire of mass 200 g and length 1.5 m carries a current of 2A. It is suspended in mid air by a uniform magnetic field B. What is the magnitude of the magnetic field?

[CBSE (F) 2015] [HOTS]



Ans. (a) From Flemings left hand rule, the electron deflects in anticlockwise direction.

As the electron comes out the magnetic field region, it will describe a semi-circular path.



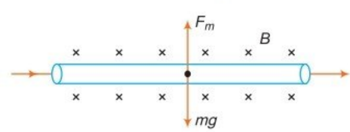
Magnetic force provides a centripetal force. So,

$$evB = \frac{mv^2}{r} \quad \text{or} \quad eB = \frac{mv}{r}$$

Time taken, $T = \frac{\pi r}{v} = \frac{\pi m}{eB}$

$$T = \frac{3.14 \times 9.1 \times 10^{-31}}{1.6 \times 10^{-19} \times 10^{-5}}$$

$$= \frac{3.14 \times 9.1 \times 10^{-7}}{1.6} = \mathbf{1.78 \times 10^{-6}\ s}$$



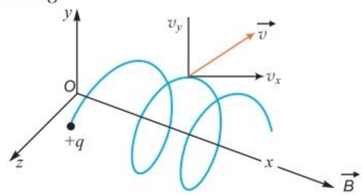
(b) If Ampere's force acts in upward direction and balances the weight, that is,

$$F_m = mg$$

$$BIl = mg \quad \Rightarrow \quad B = \frac{mg}{Il} = \frac{0.2 \times 10}{2 \times 1.5} = \frac{2}{3} = \mathbf{0.67\ T}$$

Q. 12. A uniform magnetic field $\vec{B}$ is set up along the positive x-axis. A particle of charge 'q' and mass 'm' moving with a velocity $\vec{v}$ enters the field at the origin in X-Y plane such that it has velocity components both along and perpendicular to the magnetic field $\vec{B}$. Trace, giving reason, the trajectory followed by the particle. Find out the expression for the distance moved by the particle along the magnetic field in one rotation. **[CBSE Allahabad 2015] [HOTS]**

Ans. If component v_x of the velocity vector is along the magnetic field, and remain constant, the charge particle will follow a helical trajectory; as shown in fig.



If the velocity component v_y is perpendicular to the magnetic field B, the magnetic force acts like a centripetal force $qv_y B$.

So, $$qv_y B = \frac{mv_y^2}{r} \Rightarrow v_y = \frac{qBr}{m}$$

Since tangent velocity $v_y = r\omega$

$$\Rightarrow \quad r\omega = \frac{qBr}{m} \quad \Rightarrow \quad \omega = \frac{qB}{m}$$

Time taken for one revolution, $T = \dfrac{2\pi}{\omega} = \dfrac{2\pi m}{qB}$

and the distance moved along the magnetic field in the helical path is

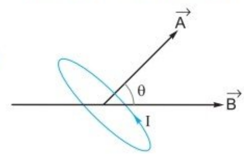
$$x = v_x . T = v_x . \frac{2\pi m}{qB}$$

Q. 13. (a) (i) A circular loop of area $\vec{A}$, carrying a current I is placed in a uniform magnetic field $\vec{B}$. Write the expression for the torque $\vec{\tau}$ acting on it in a vector form.

(ii) If the loop is free to turn, what would be its orientation of stable equilibrium? Show that in this orientation, the flux of net field (external field + the field produced by the loop) is maximum.

(b) Find out the expression for the magnetic field due to a long solenoid carrying a current I and having n number of turns per unit length. **[*CBSE (F) 2013*] [*HOTS*]**

Ans. (*a*) (*i*) Torque acting on the current loop $\vec{\tau} = \vec{m} \times \vec{B} = I(\vec{A} \times \vec{B})$



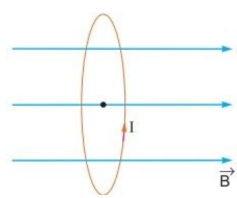
(*ii*) If magnetic moment $\vec{m} = I\vec{A}$ is in the direction of external magnetic field *i.e.*, $\theta = 0°$.

Magnetic flux $\phi_B = (\vec{B}_{ext} + B_C) \cdot \vec{A}$

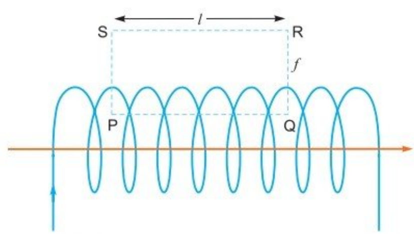
$$\phi_{max} = \left[|\vec{B}_{ext}| + \frac{\mu_0 I}{2r} \right] |A| \cos 0°$$

where r is radius of the loop.

(*b*) On applying Ampere's circuital law $\oint \vec{B}.\vec{dl} = \mu_0$ [Total current]



$$\Rightarrow \quad \int_{PQ} \vec{B}.\vec{dl} + \int_{QR} \vec{B}.\vec{dl} + \int_{RS} \vec{B}.\vec{dl} + \int_{SP} \vec{B}.\vec{dl} = \mu_0 [n\ell I]$$



As no magnetic field exists in direction QR, RS and SP, so

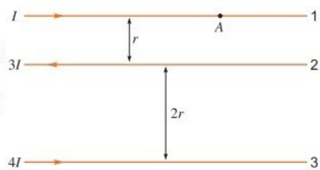
$$\int_0^l |\vec{B}| dl + 0 + 0 + 0 = \mu_0 n\ell I$$

$$\Rightarrow \quad |\vec{B}| \ell = \mu_0 n\ell I \quad \Rightarrow \quad B = \mu_0 nI$$

Q. 14. The figure shows three infinitely long straight parallel current carrying conductors. Find the

(i) magnitude and direction of the net magnetic field at point A lying on conductor 1,

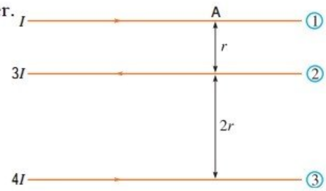
(ii) magnetic force on conductor 2. **[CBSE (F) 2017]**



Ans. (i) Magnetic field,

$$B_2 = \frac{\mu_0}{4\pi}\frac{2(3I)}{r} = \frac{\mu_0(6I)}{4\pi r} \text{ into the plane of the paper.}$$

$$B_3 = \frac{\mu_0}{4\pi}\frac{2(4I)}{3r} = \frac{\mu_0}{4\pi}\left(\frac{8I}{3r}\right) \text{ out of the plane of the paper.}$$



$$B_A = B_2 - B_3$$

$$= \boldsymbol{\frac{\mu_0}{4\pi}\frac{10I}{3r}} \text{ into the paper.}$$

(ii) Magnetic force per unit length on wire (2)

$$F = \frac{\mu_0}{2\pi r}.3I^2 - \frac{\mu_0 12I^2}{2\pi(2r)}$$

$$= \frac{3}{2}\frac{\mu_0 I^2}{\pi r} - 3\frac{\mu_0 I^2}{\pi r} = \boldsymbol{-\frac{3}{2}\frac{\mu_0 I^2}{\pi r}}$$

Hence, $F = \frac{3}{2}\frac{\mu_0 I^2}{\pi r}$ in the direction of wire (1).

Q. 15. (a) State the condition under which a charged particle moving with velocity v goes undeflected in a magnetic field B.

(b) An electron, after being accelerated through a potential difference of 10^4 V, enter a uniform magnetic field of 0.04 T, perpendicular to its direction of motion. Calculate the radius of curvature of its trajectory. **[CBSE (AI) 2017]**

Ans. (a) Force in magnetic field on a charged particle

$$\vec{F} = q(\vec{v} \times \vec{B}) \qquad \Rightarrow F = qvB\sin\theta$$

If $F = 0$,

$$\Rightarrow \qquad 0 = qvB\sin\theta$$

$$\Rightarrow \qquad \sin\theta = 0 \quad \Rightarrow \quad \theta = \pm n\pi$$

So, magnetic field will be parallel or antiparallel to the velocity of charged particle.

(b) For a charged particle moving in a constant magnetic field and $\vec{v} \perp \vec{B}$

$$\frac{mv^2}{r} = qvB \quad \Rightarrow \quad r = \frac{mv}{qB} = \frac{p}{qB} \qquad ...(i)$$

If e is accelerated through a potential difference of 10^4 V, then

K. E of electron $= eV$

$$\Rightarrow \qquad \frac{p^2}{2m} = eV \quad \Rightarrow \quad p = \sqrt{2meV} \qquad ...(ii)$$

From (i) & (ii)

$$\Rightarrow \quad r = \frac{\sqrt{2meV}}{qB}$$

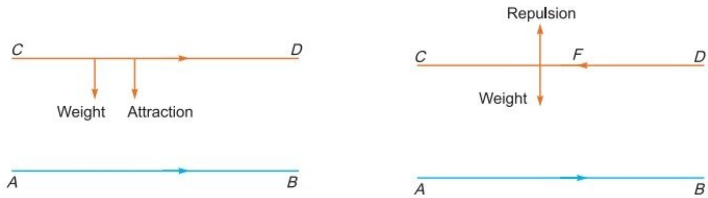
$$= \frac{\sqrt{2\times9.1\times10^{-31}\times1.6\times10^{-19}\times10^4}}{1.6\times10^{-19}\times0.04}$$

$$= \frac{5.39\times10^{-23}}{6.4\times10^{-21}}\text{ m} = \mathbf{8.4\times10^{-3}\ m}$$

Q. 16. A wire AB is carrying a steady current of 12 A and is lying on the table. Another wire CD carrying 5 A is held directly above AB at a height of 1 mm. Find the mass per unit length of the wire CD so that it remains suspended at its position when left free. Give the direction of the current flowing in CD with respect to that in AB. [Take the value of g = 10 ms^{-2}]

[*CBSE (AI) 2013*]

Ans. Current carrying conductors repel each other, if current flows in the opposite direction.



Current carrying conductors attract each other if current flows in the same direction.

If wire CD remain suspended above AB then

$$F_{repulsion} = \text{Weight}$$

$$\frac{\mu_0 I_1 I_2 l}{2\pi r} = mg \qquad \text{where } r = \text{Separation between the wires}$$

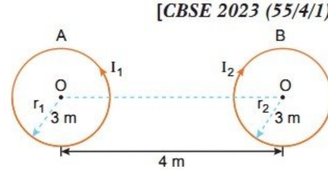
$$\therefore \qquad \frac{m}{l} = \frac{\mu_0 I_1 I_2}{2\pi r g}$$

$$= \frac{2 \times 10^{-7} \times 12 \times 5}{1 \times 10^{-3} \times 10}$$

$$= \mathbf{1.2 \times 10^{-3}\ kg / m}$$

Current in CD should be in opposite direction to that in AB.

Q. 17. Two circular loops A and B, each of radius 3 m, are placed coaxially at a distance of 4 m. They carry currents of 3 A and 2 A in opposite directions respectively. Find the net magnetic field at the centre of loop A. **[*CBSE 2023 (55/4/1)*]**



Ans. Given, $I_1 = 3$ A, $I_2 = 2$ A

$x = 4$ m, $r_1 = 3$ m, $r_2 = 3$ m

Magnetic field at centre of A due to A,

$$B_1 = \frac{\mu_o I_1}{2r} = \frac{4\pi \times 10^{-7} \times 3}{2 \times 3} = 2\pi \times 10^{-7}\ \text{T (outward)}$$

Magnetic field at centre of A due to B,

$$B_2 = \frac{\mu_o I_2 R^2}{2(x^2 + R^2)^{3/2}} \frac{4\pi \times 10^{-7} \times 2 \times 9}{2\,(16+9)^{3/2}} = \frac{4\pi \times 10^{-7} \times 9}{125}\ \text{T (inward)}$$

Now, net magnetic field at centre of A,

$$\therefore \quad B = B_1 - B_2 = 2\pi \times 10^{-7}\left(1 - \frac{18}{125}\right)$$

$$= 2\pi \times 10^{-7}\left(\frac{125-18}{125}\right)$$

$$= \frac{2\pi \times 10^{-7} \times 107}{125} = \mathbf{5.4 \times 10^{-7}\ T}\ \text{(outward)}$$

Q. 18. The magnitude F of the force between two straight parallel current carrying conductors kept at a distance d apart in air is given by

$$F = \frac{\mu_0 I_1 I_2}{2\pi d}$$

where I_1 and I_2 are the currents flowing through the two wires.

Use this expression, and the sign convention that the:

"Force of attraction is assigned a negative sign and force of repulsion is assigned a positive sign".

Draw graphs showing dependence of F on

(*i*) $I_1 I_2$ when d is kept constant

(*ii*) d when the product $I_1 I_2$ is maintained at a constant positive value.

(*iii*) d when the product $I_1 I_2$ is maintained at a constant negative value.

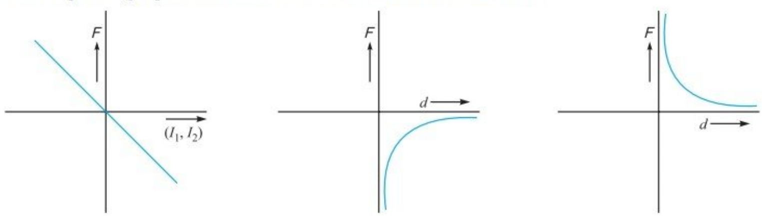
[*CBSE Sample Paper*] [*HOTS*]

Ans. We know that F is an **attractive (–ve)** force when the currents I_1 and I_2 are 'like' currents *i.e.*, when the product $I_1 I_2$ is positive.

Similarly F is a **repulsive (+ve)** force when the currents I_1 and I_2 are 'unlike' currents, *i.e.*, when the product $I_1 I_2$ is negative.

Now $F \propto (I_1 I_2)$, when d is kept constant and $F \propto \frac{1}{d}$ when $I_1 I_2$ is kept constant.

The required graphs, therefore, have the forms shown below:



(*i*) (*ii*) (*iii*)

Q. 19. (*a*) Briefly explain how a galvanometer is converted into an ammeter. [*CBSE 2023 (55/2/1)*]

(*b*) A galvanometer coil has a resistance of 15 Ω and it shows full scale deflection for a current of 4 mA. Convert it into an ammeter of range 0 to 6 A. [*CBSE 2019 (55/4/1)*]

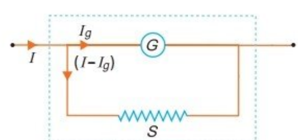
Ans. (*a*) By connecting a small resistance called shunt (S) in parallel to coil of the galvanometer. The value of S is related to the maximum current (I) to be measured as $S = \frac{I_g G}{I - I_g}$.

(*b*) Given,

$$G = 15\,\Omega$$

$$I_g = 4\times10^{-3}\,\text{A}$$

$$I = 6\,\text{A}$$



Ammeter

$$\because \quad I_g G = (I - I_g)S$$

$$S = \frac{I_g G}{I - I_g} = \frac{4\times10^{-3}\times15}{6-4\times10^{-3}}$$

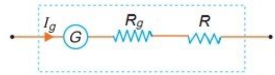
$$= 0.01\,\Omega$$

The galvanometer can be converted into ammeter of given range by connecting a shunt resistance of 0.01 Ω in parallel.

Q. 20. **(a) Briefly explain how a galvanometer is converted into a voltmeter.**

(b) A voltmeter of a certain range is constructed by connecting a resistance of 980 Ω in series with a galvanometer. When the resistance of 470 Ω is connected in series, the range gets halved. Find the resistance of the galvanometer. **[*CBSE 2019 (55/4/1)*]**

Ans. (*a*) A galvanometer may be converted into voltmeter by connecting a high value resistance R in series with coil of the galvanometer. The value of (R) is related to the maximum voltage (V) to be measured as $R = \frac{V}{I_g} - G$.



Voltmeter

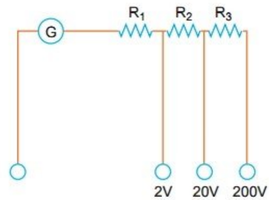
(*b*) $$I_g = \frac{V}{R_g + R}$$

$$\Rightarrow \quad \frac{V}{R_g + 980} = \frac{V}{2(R_g + 470)}$$

$$\Rightarrow \quad 2R_g + 940 = R_g + 980 \quad \Rightarrow \quad R_g = \mathbf{40\ \Omega}$$

Q. 21. **A multirange voltmeter can be constructed by using a galvanometer circuit as shown in the figure. We want to construct a voltmeter that can measure 2 V, 20 V and 200 V using a galvanometer of resistance 10 Ω and that produces maximum deflection for current of 1 mA. Find the value of R_1, R_2 and R_3 that have to be used.**

[*NCERT Exemplar, CBSE Sample Paper 2018*]



Ans. Here, $G = 10\ \Omega$, $I_g = 1\ \text{mA} = 10^{-3}$ A

Case (*i*), $V = 2$ V

$$R_1 = \frac{V}{I_g} - G = \frac{2}{10^{-3}} - 10 = 1990\ \Omega \approxeq \mathbf{2\ k\ \Omega}$$

Case (*ii*) $V = 20$ V

$$(R_1 + R_2) = \frac{20}{10^{-3}} - 10 = 20{,}000 - 10 \approx 20\ \text{k}\Omega$$

$\therefore$ $$R_2 = 20\ \text{k}\Omega - 2\ \text{k}\Omega = \mathbf{18\ k\ \Omega}$$

Case (*iii*) $V = 200$ V

$\therefore$ $$R_1 + R_2 + R_3 = \frac{200}{10^{-3}} - 10 \approx 200\ \text{k}\Omega$$

$\therefore$ $$R_3 = 200\ \text{k}\Omega - 20\ \text{k}\Omega \approxeq \mathbf{180\ k\ \Omega}$$

CONSTRUCTED RESPONSE QUESTIONS AS PER NEP

Long Answer Questions

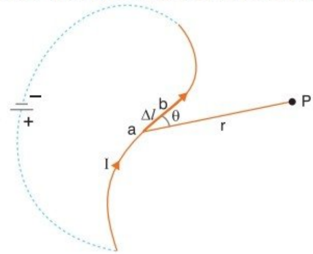
Each of the following questions are of 5 marks.

Q. 1. **State and explain Biot-Savart law. Use it to derive an expression for the magnetic field produced at a point near a long current carrying wire.** **[*CBSE 2019 (55/3/1)*]**

Ans. **Biot-Savart law:** Suppose the current I is flowing in a conductor and there is a small current element '*ab*' of length Δl. According to Biot-Savart the magnetic field (ΔB) produced due to this current element at a point P distant r from the element is given by

$$\Delta B \propto \frac{I \Delta l \sin\theta}{r^2} \text{ or } \Delta B = \frac{\mu}{4\pi} \frac{I\, \Delta l \sin\theta}{r^2} \qquad ...(i)$$

where $\frac{\mu}{4\pi}$ is a constant of proportionality. It depends on the medium between the current element and point of observation (P). μ is called the permeability of medium. Equation (*i*) is called Biot-Savart law. The product of current (I) and length element (Δl) (*i.e.*, $I\ \Delta l$) is called the **current element**. Current element is a vector quantity, its direction is along the direction of current. If the conductor be placed in vacuum (or air), then μ is replaced by μ_0; where μ_0 is called the permeability of free space (or air). In S.I. system $\mu_0 = 4\pi \times 10^{-7}$ weber/ampere-metre (or newton/ampere^2).



Thus $\frac{\mu_0}{4\pi} = 10^{-7}$ weber/ampere × metre

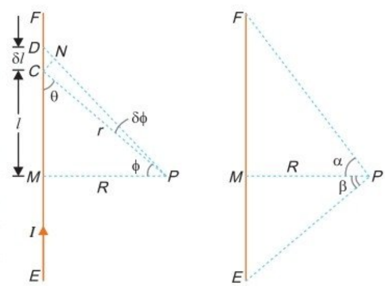
As in most cases the medium surrounding the conductor is air, therefore, in general, Biot-Savart law is written as

$$\Delta B = \frac{\mu_0}{4\pi}\frac{I\Delta l \sin\theta}{r^2}$$

The direction of magnetic field is perpendicular to the plane containing current element and the line joining point of observation to current element. So in vector form the expression for magnetic field takes the form

$$\Delta\vec{B} = \frac{\mu_0}{4\pi}\frac{I\Delta\vec{l}\times\vec{r}}{r^3}$$

Derivation of formula for magnetic field due to a current carrying wire using Biot-Savart law: Consider a wire EF carrying current I in upward direction. The point of observation is P at a finite distance R from the wire. If PM is perpendicular dropped from P on wire; then $PM = R$. The wire may be supposed to be formed of a large number of small current elements. Consider a small element CD of length δl at a distance l from M.



(a) (b)

Let $\angle CPM = \phi$

and $\angle CPD = \delta\phi,\ \angle PDM = \theta$

The length δl is very small, so that $\angle PCM$ may also be taken equal to θ.

The perpendicular dropped from C on PD is CN. The angle formed between element $I\ \vec{\delta l}$ and $\vec{r}\,(=\vec{CP})$ is $(\pi - \theta)$. Therefore according to Biot-Savart law, the magnetic field due to current element $I\vec{\delta l}$ at P is

$$\delta B = \frac{\mu_0}{4\pi}\frac{I\ \delta l \sin(\pi-\theta)}{r^2} = \frac{\mu_0}{4\pi}\frac{I\ \delta l \sin\theta}{r^2} \qquad ...(i)$$

But in $\Delta\ CND,\ \sin\theta = \sin(\angle CDN) = \frac{CN}{CD} = \frac{r\ \delta\phi}{\delta l}$

or $\quad \delta l \sin\theta = r\ \delta\phi$

∴ From equation (*i*)

$$\delta B = \frac{\mu_0}{4\pi}\frac{I\ r\ \delta\phi}{r^2} = \frac{\mu_0}{4\pi}\frac{I\ \delta\phi}{r} \qquad ...(ii)$$

Again from fig.

$$\cos\phi = \frac{R}{r} \Rightarrow r = \frac{R}{\cos\phi}$$

From equation (*ii*),

$$\delta B = \frac{\mu_0}{4\pi}\frac{I\cos\phi\,\delta\phi}{R}$$

If the wire is of finite length and its ends make angles α and β with line MP, then net magnetic field (B) at P is obtained by summing over magnetic fields due to all current elements, *i.e.*,

$$B = \int_{-\beta}^{\alpha}\frac{\mu_0}{4\pi}\frac{I\cos\phi\,d\phi}{R} = \frac{\mu_0 I}{4\pi R}\int_{-\beta}^{\alpha}\cos\phi\,d\phi$$

$$\frac{\mu_0 I}{4\pi R}[\sin\phi]_{-\beta}^{\alpha} = \frac{\mu_0 I}{4\pi R}[\sin\alpha - \sin(-\beta)]$$

i.e., $$B = \frac{\mu_0 I}{4\pi R}(\sin\alpha + \sin\beta)$$

This is expression for magnetic field due to current carrying wire of finite length.

If the wire is of infinite length (or very long), then $\alpha = \beta \Rightarrow \pi/2$

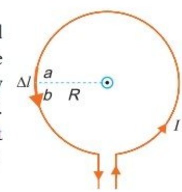
$\therefore$ $$B = \frac{\mu_0 I}{4\pi R}\left(\sin\frac{\pi}{2} + \sin\frac{\pi}{2}\right) = \frac{\mu_0 I}{4\pi R}[1+1] \quad \text{or} \quad B = \frac{\mu_0 I}{2\pi R}$$

Q. 2. (*i*) State Biot-Savart Law. Using this law, find an expression for the magnetic field at the centre of a circular coil of *N*-turns, radius *R*, carrying current *I*. [*CBSE 2019 (55/1/1), 2023 (55/1/1)*]

(*ii*) Sketch the magnetic field for a circular current loop, clearly indicating the direction of the field. [*CBSE (F) 2010, Central 2016, 2023 (55/1/1)*]

Ans. (*i*) **Biot-Savart Law:** Refer to above question

Magnetic field at the centre of circular loop: Consider a circular coil of radius R carrying current I in anticlockwise direction. Say, O is the centre of coil, at which magnetic field is to be computed. The coil may be supposed to be formed of a large number of current elements. Consider a small current element '*ab*' of length Δl. According to Biot Savart law the magnetic field due to current element '*ab*' at centre O is



$$\Delta B = \frac{\mu_0}{4\pi}\frac{I\,\Delta l\sin\theta}{R^2}$$

where θ is angle between current element ab and the line joining the element to the centre O. Here $\theta = 90°$ because current element at each point of circular path is perpendicular to the radius. Therefore magnetic field produced at O, due to current element ab is

$$\Delta B = \frac{\mu_0}{4\pi}\frac{I\,\Delta l}{R^2}$$

According to Maxwell's right hand rule, the direction of magnetic field at O is upward, perpendicular to the plane of coil. The direction of magnetic field due to all current elements is the same. Therefore the resultant magnetic field at the centre will be the sum of magnetic fields due to all current elements. Thus

$$B = \Sigma\Delta B = \Sigma\frac{\mu_0}{4\pi}\frac{I\,\Delta l}{R^2} = \frac{\mu_0}{4\pi}\frac{I}{R^2}\Sigma\,\Delta l$$

But $\Sigma\Delta l$ = total length of circular coil = 2πR (for one-turn)

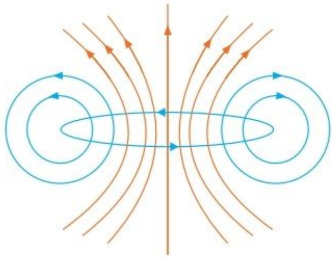
$\therefore$ $$B = \frac{\mu_0}{4\pi}\frac{I}{R^2}.2\pi R \quad \text{or} \quad B = \frac{\mu_0 I}{2R}$$

If the coil contains N–turns, then $\sum \Delta l = N.\ 2\pi R$

$$B = \frac{\mu_0 I}{4\pi R^2}.N.2\pi R \quad \text{or} \quad B = \frac{\mu_0 NI}{2R}$$

Here current in the coil is anticlockwise and the direction of magnetic field is perpendicular to the plane of coil upward; but if the current in the coil is clockwise, then the direction of magnetic field will be perpendicular to the plane of coil downward.

(*ii*) **Magnetic field lines due to a circular current loop:**

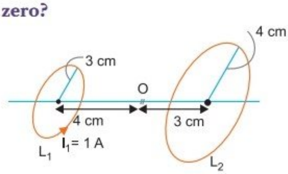


Q. 3. (*i*) Derive an expression for the magnetic field at a point on the axis of a current carrying circular loop. [*CBSE 2019 (55/3/1), 2023 (55/3/1)*]

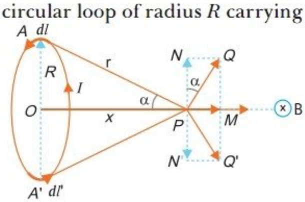
OR

Using Biot-Savart's law, derive an expression for magnetic field at any point on axial line of a current carrying circular loop. Hence, find magnitude of magnetic field intensity at the centre of circular coil. [*CBSE Sample Paper 2020*]

(*ii*) Two co-axial circular loops L_1 and L_2 of radii 3 cm and 4 cm are placed as shown. What should be the magnitude and direction of the current in the loop L_2 so that the net magnetic field at the point O be zero?



Ans. (*i*) **Magnetic field at the axis of a circular loop:** Consider a circular loop of radius R carrying current I, with its plane perpendicular to the plane of paper. Let P be a point of observation on the axis of this circular loop at a distance x from its centre O. Consider a small element of length dl of the coil at point A. The magnitude of the magnetic induction $\overrightarrow{dB}$ at point P due to this element is given by



$$\overrightarrow{dB} = \frac{\mu_0}{4\pi}\frac{I\,dl\sin\alpha}{r^2}$$

The direction of $\overrightarrow{dB}$ is perpendicular to the plane containing $\overrightarrow{dl}$ and $\vec{r}$ and is given by right hand screw rule. As the angle between $I\overrightarrow{dl}$ and $\vec{r}$ and is 90°, the magnitude of the magnetic induction $\overrightarrow{dB}$ is given by,

$$\overrightarrow{dB} = \frac{\mu_0 I}{4\pi}\frac{dl\sin 90^\circ}{r^2} = \frac{\mu_0 I\,dl}{4\pi r^2}.$$

If we consider the magnetic induction produced by the whole of the circular coil, then by symmetry the components of magnetic induction perpendicular to the axis will be cancelled out, while those parallel to the axis will be added up. Thus the resultant magnetic induction $\vec{B}$ at axial point P is along the axis and may be evaluated as follows:

The component of $d\vec{B}$ along the axis,

$$d\vec{B}_x = \frac{\mu_0 I\,dl}{4\pi r^2}\sin\alpha$$

But $\sin\alpha = \frac{R}{r}$ and $r = (R^2 + x^2)^{1/2}$

$$\therefore \qquad d\vec{B}_x = \frac{\mu_0 I dl}{4\pi r^2}\cdot\frac{R}{r} = \frac{\mu_0 IR}{4\pi r^3}dl = \frac{\mu_0 IR}{4\pi (R^2 + x^2)^{3/2}}dl$$

Therefore the magnitude of resultant magnetic induction at axial point P due to the whole circular coil is given by

$$\vec{B} = \oint \frac{\mu_0 IR}{4\pi (R^2 + x^2)^{3/2}}dl = \frac{\mu_0 IR}{4\pi (R^2 + x^2)^{3/2}}\oint dl$$

But $\qquad \oint dl = \text{length of the loop} = 2\pi R$

Therefore, $\quad B = \frac{\mu_0 IR}{4\pi (R^2 + x^2)^{3/2}}(2\pi R)$

$$\vec{B} = B_x\,\hat{i} = \frac{\mu_0 IR^2}{2(R^2 + x^2)^{3/2}}\hat{i}. \qquad \left[\text{At centre}, x = 0, \vec{B} = \frac{\mu_0 I}{2R}\right]$$

If the coil contains N turns, then

$$B = \frac{\boldsymbol{\mu_0 NIR^2}}{\boldsymbol{2(R^2 + x^2)^{3/2}}} \textbf{ tesla.}$$

(ii) The magnetic field, $B = \frac{\mu_0 NIa^2}{2(a^2 + x^2)^{3/2}}$

Here $N = 1, a_1 = 3$ cm, $x_1 = 4$ cm, $I_1 = 1$ A

$\therefore$ Magnetic field at O due to coil L_1 is

$$B_1 = \frac{\mu_0 \times 1 \times (3 \times 10^{-2})^2}{2\left[(3 \times 10^{-2})^2 + (4 \times 10^{-2})^2\right]^{3/2}} = \frac{\mu_0 (9 \times 10^{-4})}{2 \times 125 \times 10^{-6}}$$

Magnetic field at O due to coil L_2 is

Here $a_2 = 4$ cm, $x_2 = 3$ cm

$$B_2 = \frac{\mu_0 \times I_2 (4 \times 10^{-2})^2}{2\left[(4 \times 10^{-2})^2 + (3 \times 10^{-2})^2\right]^{3/2}}$$

$$= \frac{\mu_0 I_2 \times 16 \times 10^{-4}}{2 \times 125 \times 10^{-6}}$$

For zero magnetic field at O, the currents I_1 and I_2 should be in same direction, so current I_2 should be in opposite directions and satisfy the condition,

$$B_1 = B_2$$

$$\Rightarrow \qquad \frac{\mu_0 \times 9 \times 10^{-4}}{2 \times 125 \times 10^{-4}} = \frac{\mu_0 I_2 \times 16 \times 10^{-4}}{2 \times 125 \times 10^{-4}} \Rightarrow I_2 = \frac{\mathbf{9}}{\mathbf{16}}\ \textbf{A}$$

Q. 4. **(*a*) A straight thick long wire of uniform circular cross-section of radius '*a*' is carrying a steady current *I*. The current is uniformly distributed across the cross-section. Use Ampere's circuital law to obtain a relation showing the variation of the magnetic field (B_r) inside and outside the wire with distance *r*, ($r \le a$) and ($r > a$) of the field point from the centre of its cross-section. What is the magnetic field at the surface of this wire? Plot a graph showing the nature of this variation.**

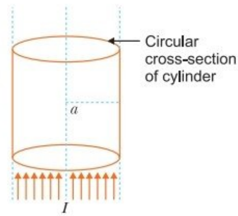
(*b*) Calculate the ratio of magnetic field at a point $\frac{a}{2}$ above the surface of the wire to that at a point $\frac{a}{2}$ below its surface. What is the maximum value of the field of this wire?

[*CBSE Delhi 2010; Chennai 2015*]

Ans. (*a*) **Magnetic field due to a straight thick wire of uniform cross-section:** Consider an infinitely long cylindrical wire of radius *a*, carrying current *I*. Suppose that the current is uniformly distributed over whole cross-section of the wire. The cross-section of wire is circular. Current per unit cross-sectional area.

$$i = \frac{I}{\pi a^2} \qquad \ldots(i)$$

Magnetic field at external points ($r > a$): We consider a circular path of radius *r* ($> a$) passing through external point P concentric with circular cross-section of wire. By symmetry the strength of magnetic field at every point of circular path is same and the direction of magnetic field is tangential to path at every point. So line integral of magnetic field $\vec{B}$ around the circular path



$$\oint \vec{B}.\vec{dl} = \oint B\, dl \cos 0^\circ = B\, 2\pi r$$

Current enclosed by path = Total current on circular cross-section of cylinder = *I*

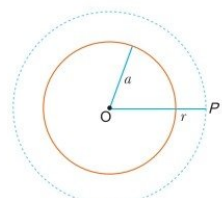
By Ampere's circuital law

$$\oint \vec{B}.\vec{dl} = \mu \times \text{current enclosed by path}$$

$$\Rightarrow \qquad B\, 2\pi r = \mu_0 \times I \quad \Rightarrow \quad B = \frac{\mu_0 I}{2\pi r}$$

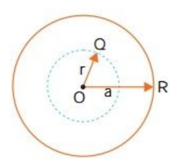
This expression is same as the magnetic field due to a long current carrying straight wire.

This shows that *for external points the current flowing in wire may be supposed to be concerned at the axis of cylinder.*



Magnetic Field at Internal Points ($r < a$) : Consider a circular path of radius *r* ($<a$), passing through internal point *Q* concentric with circular cross-section of the wire. In this case the assumed circular path encloses only a path of current carrying circular cross-section of the wire.

$$\therefore \text{ Current enclosed by path} = i \times \pi r^2 = \left(\frac{I}{\pi a^2}\right) \times \pi r^2 = \frac{Ir^2}{a^2}$$



$\therefore$ By Ampere's circuital law

$$\oint \vec{B}.\vec{dl} = \mu_0 \times \text{ current closed by path}$$

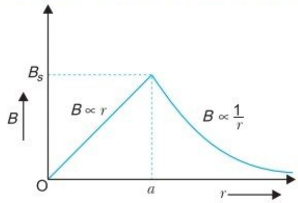
$$\Rightarrow \qquad B.2\pi r = \mu_0 \times \frac{Ir^2}{a^2} \quad \Rightarrow \quad B = \frac{\mu_0 I r}{2\pi a^2}$$

Clearly, magnetic field strength inside the current carrying wire is directly proportional to distance of the point from the axis of wire.

At surface of cylinder $r = a$, so magnetic field at surface of wire

$$B_S = \frac{\mu_0 I}{2\pi a} \text{ (maximum value)}$$

The variation of magnetic field strength (B) with distance (r) from the axis of wire for internal and external points is shown in figure.



(b) $B_{Outside} = \dfrac{\mu_0 I}{2\pi r} = \dfrac{\mu_0 I}{2\pi\left(a + \dfrac{a}{2}\right)} = \dfrac{\mu_0 I}{3\pi a}$

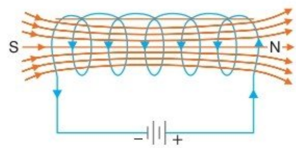
$B_{inside} = \dfrac{\mu_0 I r}{2\pi a^2} = \dfrac{\mu_0 I (a/2)}{2\pi a^2} = \dfrac{\mu_0 I}{4\pi a}$

$\therefore \quad \dfrac{B_{outside}}{B_{inside}} = \mathbf{\dfrac{4}{3}}$

Maximum value of magnetic field is at the surface given by $B_S = \mathbf{\dfrac{\mu_0 I}{2\pi a}}$.

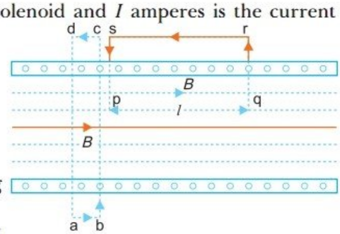
Q. 5. Using Ampere's circuital law find an expression for the magnetic field at a point on the axis of a long solenoid with closely wound turns. ***[CBSE (F) 2010, 2019(55/2/1)]***

Ans. Magnetic field due to a current carrying long solenoid:



A solenoid is a long wire wound in the form of a close-packed helix, carrying current. To construct a solenoid a large number of closely packed turns of insulated copper wire are wound on a cylindrical tube of card-board or china clay. When an electric current is passed through the solenoid, a magnetic field is produced within the solenoid. If the solenoid is long and the successive insulated copper turns have no gaps, then the magnetic field within the solenoid is uniform; with practically no magnetic field outside it. The reason is that the solenoid may be supposed to be formed of a large number of circular current elements. The magnetic field due to a circular loop is along its axis and the current in upper and lower straight parts of solenoid is equal and opposite. Due to this the magnetic field in a direction perpendicular to the axis of solenoid is zero and so the resultant magnetic field is along the axis of the solenoid.

If there are 'n' number of turns per metre length of solenoid and I amperes is the current flowing, then magnetic field at axis of long solenoid



$$\mathrm{B} = \mu_0 n I$$

If there are N turns in length l of wire, then

$$n = \frac{N}{l} \quad \text{or} \quad B = \frac{\mu_0 N I}{l}$$

Derivation: Consider a symmetrical long solenoid having number of turns per unit length equal to n.

Let I be the current flowing in the solenoid, then by right hand rule, the magnetic field is parallel to the axis of the solenoid.

Field outside the solenoid: Consider a closed path *abcd*. Applying Ampere's law to this path

$\oint \vec{B}.\vec{dl} = \mu \times 0$ (since net current enclosed by path is zero)

As $\quad dl \neq 0 \therefore B = 0$

This means that the magnetic field outside the solenoid is zero.

Field inside the solenoid: Consider a closed path *pqrs* The line integral of magnetic field $\vec{B}$ along path *pqrs* is

$$\oint_{pqrs} \vec{B}.\vec{dl} = \int_{pq} \vec{B}.\vec{dl} + \int_{qr} \vec{B}.\vec{dl} + \int_{rs} \vec{B}.\vec{dl} + \int_{sp} \vec{B}.\vec{dl} \qquad ...(i)$$

For path pq, $\vec{B}$ and $\vec{dl}$ are along the same direction,

$\therefore \quad \int_{pq} \vec{B}.\vec{dl} = \int B\, dl = Bl \qquad$ where, $pq = l$ (say)

For paths qr and sp, $\vec{B}$ and $\vec{dl}$ are mutually perpendicular.

$\therefore \quad \int_{qr} \vec{B}.\vec{dl} = \int_{sp} \vec{B}.\vec{dl} = \int B\, dl \cos 90^o = 0$

For path rs, $B = 0$ (since field is zero outside a solenoid)

$\therefore \quad \int_{rs} \vec{B}.\vec{dl} = 0$

In view of these, equation (*i*) gives

$\therefore \quad \int_{pqrs} \vec{B}.\vec{dl} = \int_{pq} \vec{B}.\vec{dl} = Bl$ ...(*ii*)

By Ampere's law $\oint \vec{B}.\vec{dl} = \mu_0 \times$ net current enclosed by path

$\Rightarrow \quad Bl = \mu_0 (nl\, I) \quad \therefore B = \mu_0 \boldsymbol{nI}$

Q. 6. Derive an expression for the force acting on a current carrying straight conductor kept in a magnetic field. State the rule which is used to find the direction of this force. Give the condition under which this force is (1) maximum, and (2) minimum. ***[CBSE 2023 (55/1/1)]***

Ans. Force on a current carrying conductor on the basis of force on a moving charge: Consider a metallic conductor of length L, cross-sectional area A placed in a uniform magnetic field B and its length makes an angle θ with the direction of magnetic field B. The current in the conductor is I. According to free electron model of metals, the current in a metal is due to the motion of free electrons. When a conductor is placed in a magnetic field, the magnetic field exerts a force on every free-electron. The sum of forces acting on all electrons is the net force acting on the conductor. If v_d is the drift velocity of free electrons, then

current, $I = neAv_d$ where n is number of free electrons per unit volume. ...(*i*)

magnetic force on each electron $= ev_d B \sin\theta$

Its direction is perpendicular to both $\vec{v}_d$ and $\vec{B}$

Volume of conductor $V = AL$

Therefore, the total number of free electrons in the conductor $= nAL$

Net magnetic force on each conductor

$$F = (ev_d B \sin\theta) \,.\, (nAL) = (neAv_d).\, BL \sin\theta$$

Using equation (*i*), We get $F = IBL \sin\theta$

This is the general formula for the force acting on a current carrying conductor.

In vector form, $\quad \vec{\boldsymbol{F}} = I\, \vec{\boldsymbol{L}} \times \vec{\boldsymbol{B}}$

(1) Force will be maximum when $\sin\theta = 1$ or $\theta = 90°$. That is when length of conductor is perpendicular to magnetic field.

(2) For minimum, when, $\sin\theta = 0°$ or $\theta = 0°$ or $180°$

i.e., when length of conductor is parallel or anti parallel to magnetic field.

Q. 7. Two long straight parallel conductors carry steady current I_1 and I_2 separated by a distance d. If the currents are flowing in the same direction, show how the magnetic field set up in one produces an attractive force on the other. Obtain the expression for this force. Hence define one ampere. ***[CBSE Delhi 2016]***

OR

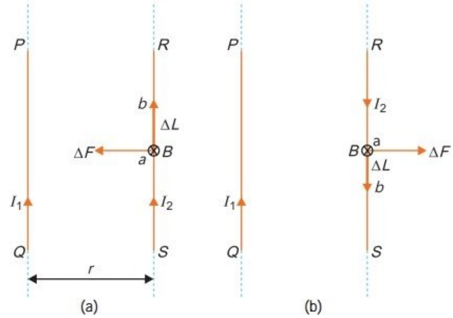
Derive an expression for the force per unit length between two long straight parallel current carrying conductors. Hence define SI unit of current (ampere).

[CBSE (AI) 2009, 2010, 2012, Patna 2015, 2020 (55/3/1)]

Ans. Suppose two long thin straight conductors (or wires) PQ and RS are placed parallel to each other in vacuum (or air) carrying currents I_1 and I_2 respectively. It has been observed experimentally that when the currents in the wire are in the same direction, they experience an attractive force (fig. *a*) and when they carry currents in opposite directions, they experience a repulsive force (fig. *b*).

Let the conductors PQ and RS carry currents I_1 and I_2 in same direction and placed at separation r. Consider a current–element 'ab' of length ΔL of wire RS. The magnetic field produced by current-carrying conductor PQ at the location of other wire RS

$$B_1 = \frac{\mu_0 I_1}{2\pi r}$$



According to Maxwell's right hand rule or right hand palm rule number 1, the direction of B_1 will be perpendicular to the plane of paper and directed downward. Due to this magnetic field, each element of other wire experiences a force. The direction of current element is perpendicular to the magnetic field; therefore the magnetic force on element ab of length ΔL

$$\Delta F = B_1 I_2 \,\Delta L \sin 90^o = \frac{\mu_0 I_1}{2\pi r} I_2 \Delta L$$

$\therefore$ The total force on conductor of length L will be

$$F = \frac{\mu_0 I_1 I_2}{2\pi r} \Sigma \Delta L = \frac{\mu_0 I_1 I_2}{2\pi r} L$$

$\therefore$ Force acting per unit length of conductor

$$f = \frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi r} \text{N/m}$$

According to Fleming's left hand rule, the direction of magnetic force will be towards PQ *i.e.*, the force will be attractive.

On the other hand if the currents I_1 and I_2 in wires are in opposite directions, the force will be repulsive. The magnitude of force in each case remains the same.

Definition of SI unit of Current (ampere): In SI system of fundamental unit of current 'ampere' is defined assuming the force between the two current carrying wires as standard.

The force between two parallel current carrying conductors of separation r is

$$f = \frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi r} \text{N/m}$$

If $I_1 = I_2 = 1$ A, $r = 1$ m, then

$$f = \frac{\mu_0}{2\pi} = \mathbf{2 \times 10^{-7}\,N/m}$$

Thus 1 ampere is the current which when flowing in each of parallel conductors placed at separation 1 m in vacuum exert a force of 2×10^{-7} on 1 m length of either wire.

Q. 8. Derive an expression for torque acting on a rectangular current carrying loop kept in a uniform magnetic field B. Indicate the direction of torque acting on the loop.

[*CBSE Delhi 2013; (F) 2009, 2019 (55/1/1), 2020 (55/1/1)*]

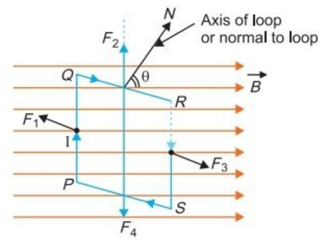
OR

Deduce the expression for the torque $\vec{\tau}$ acting on a planar loop of area $\vec{A}$ and carrying current *I* placed in a uniform magnetic field $\vec{B}$.

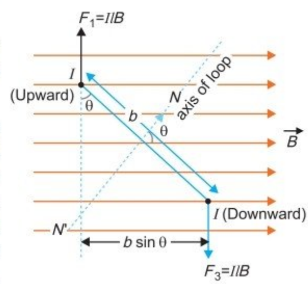
If the loop is free to rotate, what would be its orientation in stable equilibrium?

[*CBSE Ajmer 2015*]

Ans. Torque on a current carrying loop: Consider a rectangular loop *PQRS* of length *l*, breadth *b* suspended in a uniform magnetic field $\vec{B}$. The length of loop = *PQ* = *RS* = *l* and breadth *QR* = *SP* = *b*. Let at any instant the normal to the plane of loop make an angle θ with the direction of magnetic field $\vec{B}$ and *I* be the current in the loop. We know that a force acts on a current carrying wire placed in a magnetic field. Therefore, each side of the loop will experience a force. The net force and torque acting on the loop will be determined by the forces acting on all sides of the loop. Suppose that the forces on sides *PQ*, *QR*, *RS* and *SP* are $\vec{F}_1, \vec{F}_2, \vec{F}_3$ and $\vec{F}_4$ respectively. The sides *QR* and *SP* make angle (90°– θ) with the direction of magnetic field. Therefore each of the forces $\vec{F}_2$ and $\vec{F}_4$ acting on these sides has same magnitude $F' = Blb \sin(90° - \theta) = Blb \cos\theta$. According to Fleming's left hand rule the forces $\vec{F}_2$ and $\vec{F}_4$ are equal and opposite but their line of action is same. Therefore these forces cancel each other *i.e.*, the resultant of $\vec{F}_2$ and $\vec{F}_4$ is zero.



The sides *PQ* and *RS* of current loop are perpendicular to the magnetic field, therefore the magnitude of each of forces $\vec{F}_1$ and $\vec{F}_3$ is $F = IlB \sin 90° = IlB$.



According to Fleming's left hand rule the forces $\vec{F}_1$ and $\vec{F}_3$ acting on sides *PQ* and *RS* are equal and opposite, but their lines of action are different; therefore the resultant force of $\vec{F}_1$ and $\vec{F}_3$ is zero, but they form a couple called the ***deflecting couple***. When the normal to plane of loop makes an angle with the direction of magnetic field the perpendicular distance between F_1 and F_3 is $b \sin\theta$.

∴ Moment of couple or Torque,

τ = (Magnitude of one force F) × perpendicular distance $= (BIl).(b\sin\theta) = I(lb)B\sin\theta$

But lb = area of loop $= A$ (say)

∴ Torque, $\tau = IAB\sin\theta$

If the loop contains *N*-turns, then $\tau = NI\,AB\sin\theta$

In vector form $\vec{\tau} = NI\vec{A} \times \vec{B}$

The magnetic dipole moment of rectangular current loop $= M = NIA$

∴ $\vec{\tau} = \vec{M} \times \vec{B}$

Direction of torque is perpendicular to direction of area of loop as well as the direction of magnetic field *i.e.*, along $I\vec{A} \times \vec{B}$.

The current loop would be in stable equilibrium, if magnetic dipole moment is in the direction of the magnetic field $(\vec{B})$.

Q. 9. Draw the labelled diagram of a moving coil galvanometer. Prove that in a radial magnetic field, the deflection of the coil is directly proportional to the current flowing in the coil. ***[CBSE (F) 2012]***

OR

(*a*) Draw a labelled diagram of a moving coil galvanometer. Describe briefly its principle and working.

(*b*) Answer the following:

(*i*) Why is it necessary to introduce a cylindrical soft iron core inside the coil of a galvanometer?

(*ii*) Increasing the current sensitivity of a galvanometer may not necessarily increase its voltage sensitivity. Explain, giving reason. ***[CBSE (AI) 2014]***

OR

Explain, using a labelled diagram, the principle and working of a moving coil galvanometer. What is the function of (*i*) uniform radial magnetic field, (*ii*) soft iron core?

Define the terms (*i*) current sensitivity and (*ii*) voltage sensitivity of a galvanometer. Why does increasing the current sensitivity not necessarily increase voltage sensitivity?

[CBSE Allahabad 2015, 2019 (55/1/2)]

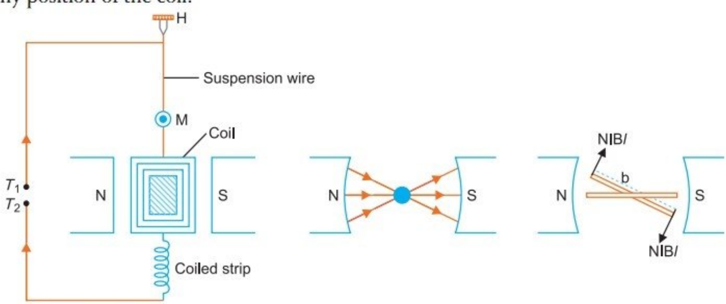
Ans. • **Moving coil galvanometer:** A galvanometer is used to detect current in a circuit.

Construction: It consists of a rectangular coil wound on a non-conducting metallic frame and is suspended by phosphor bronze strip between the pole-pieces (N and S) of a strong permanent magnet.

A soft iron core in cylindrical form is placed between the coil.

One end of coil is attached to suspension wire which also serves as one terminal (T_1) of galvanometer. The other end of coil is connected to a loosely coiled strip, which serves as the other terminal (T_2). The other end of the suspension is attached to a torsion head which can be rotated to set the coil in zero position. A mirror (M) is fixed on the phosphor bronze strip by means of which the deflection of the coil is measured by the lamp and scale arrangement. The levelling screws are also provided at the base of the instrument.

The pole pieces of the permanent magnet are cylindrical so that the magnetic field is radial at any position of the coil.



(*a*) (*b*) (*c*)

Magnetic lines of force of radial magnetic field

Principle and working: When current (I) is passed in the coil, torque τ acts on the coil, given by $\tau = NIAB \sin\theta$

where θ is the angle between the normal to plane of coil and the magnetic field of strength B, N is the number of turns in a coil.

A current carrying coil, in the presence of a magnetic field, experiences a torque, which produces proportionate deflection.

i.e., Deflection, $\theta \propto \tau$ (Torque)

Q. 9. Draw the labelled diagram of a moving coil galvanometer. Prove that in a radial magnetic field, the deflection of the coil is directly proportional to the current flowing in the coil. ***[CBSE (F) 2012]***

OR

(*a*) Draw a labelled diagram of a moving coil galvanometer. Describe briefly its principle and working.

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(*ii*) Increasing the current sensitivity of a galvanometer may not necessarily increase its voltage sensitivity. Explain, giving reason. ***[CBSE (AI) 2014]***

OR

Explain, using a labelled diagram, the principle and working of a moving coil galvanometer. What is the function of (*i*) uniform radial magnetic field, (*ii*) soft iron core?

Define the terms (*i*) current sensitivity and (*ii*) voltage sensitivity of a galvanometer. Why does increasing the current sensitivity not necessarily increase voltage sensitivity?

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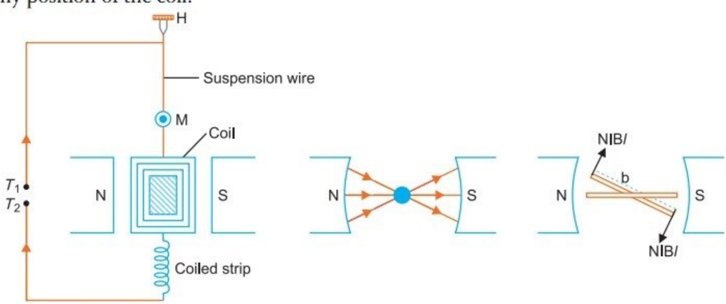


(*a*) (*b*) Magnetic lines of force of radial magnetic field (*c*)

Principle and working: When current (*I*) is passed in the coil, torque τ acts on the coil, given by $\tau = NIAB \sin\theta$

where θ is the angle between the normal to plane of coil and the magnetic field of strength *B*, *N* is the number of turns in a coil.

A current carrying coil, in the presence of a magnetic field, experiences a torque, which produces proportionate deflection.

i.e., Deflection, $\theta \propto \tau$ (Torque)

When the magnetic field is radial, as in the case of cylindrical pole pieces and soft iron core, then in every position of coil the plane of the coil, is parallel to the magnetic field lines, so that $\theta = 90°$ and $\sin 90° = 1$. The coil experiences a uniform coupler.

Deflecting torque, $\tau = NIAB$

If C is the torsional rigidity of the wire and is the twist of suspension strip, then restoring torque = $C\,\theta$

For equilibrium, deflecting torque = restoring torque

i.e. $$NIAB = C\,\theta$$

$\therefore$ $$\theta = \frac{NAB}{C} I \qquad ...(i)$$

i.e. $$\theta \propto I$$

Deflection of coil is directly proportional to current flowing in the coil and hence we can construct a linear scale.

Importance (or function) of uniform radial magnetic field: Torque for current carrying coil in a magnetic field is $\tau = NIAB \sin\theta$

In radial magnetic field $\sin\theta = 1$, so torque is $\tau = NIAB$

This makes the deflection (θ) proportional to current. In other words, the radial magnetic field makes the **scale linear**.

- The cylindrical, soft iron core makes the field radial and increases the strength of the magnetic field, *i.e.*, the magnitude of the torque.

Sensitivity of galvanometer :

Current sensitivity: It is defined as the deflection of coil per unit current flowing in it.

Sensitivity, $$S_I = \left(\frac{\theta}{I}\right) = \frac{NAB}{C} \qquad ...(ii)$$

Voltage sensitivity: It is defined as the deflection of coil per unit potential difference across its ends

i.e., $$S_V = \frac{\theta}{V} = \frac{NAB}{R_g . C}, \qquad ...(iii)$$

where R_g is resistance of galvanometer.

Clearly for greater sensitivity number of turns N, area A and magnetic field strength B should be large and torsional rigidity C of suspension should be small.

Dividing (*iii*) by (*ii*)

$$\frac{S_V}{S_I} = \frac{1}{G} \Rightarrow S_V = \frac{1}{G} S_I$$

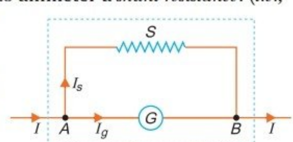
Clearly the voltage sensitivity depends on current sensitivity and the resistance of galvanometer. If we increase current sensitivity then it is not certain that voltage sensitivity will be increased. Thus, the increase of current sensitivity does not imply the increase of voltage sensitivity.

Q. 10. With the help of a circuit, show how a moving coil galvanometer can be converted into an ammeter of a given range. Write the necessary mathematical formula. [*CBSE 2023 (55/2/1)*]

Ans. Conversion of galvanometer into ammeter

An ammeter is a low resistance galvanometer and is connected in series in a circuit to read current directly.

The resistance of an ammeter is to be made as low as possible so that it may read current without any appreciable error. Therefore to convert a galvanometer into ammeter a *shunt resistance*. (*i.e.*, small resistance in parallel) is connected across the coil of galvanometer.



Ammeter

Let G be the resistance of galvanometer and I_g the current required for full scale deflection. Suppose this galvanometer is to converted into ammeter of range I ampere and the value of shunt required is S. If I_s is current in shunt, then from fig.

$$I = I_g + I_S \Rightarrow I_S = (I - I_g) \quad ...(i)$$

Also potential difference across A and B

$$(V_{AB}) = I_S . S = I_g . G$$

Substituting value of I_S from (*i*), we get

or $(I - I_g) S = I_g G$

or $IS - I_g S = I_g G$ or $IS = I_g (S+G)$

or $$I_g = \frac{S}{S+G} I$$

i.e. required shunt, $S = \dfrac{GI_g}{I - I_g}$

This is the working equation of conversion of galvanometer into ammeter.

The resistance (R_A) of ammeter so formed is given by

$$\frac{1}{R_A} = \frac{1}{S} + \frac{1}{G} \text{ or } \frac{1}{R_A} = \frac{S+G}{SG} \Rightarrow R_A = \frac{SG}{S+G}$$

If k is figure of merit of the galvanometer and n is the number of scale divisions, then $I_g = nk$. Out of the total main current I amperes, only a small permissible value I_g flows through the galvanometer and the rest $I_S = (I - I_g)$ passes through the shunt.

Remark: An ideal ammeter has zero resistance.

Q. 11. A galvanometer of resistance G is converted into a voltmeter to measure upto V volts by connecting a resistance R_1 in series with the coil. If a resistance R_2 is connected in series with it, then it can measure upto $V/2$ volts. Find the resistance, in terms of R_1 and R_2, required to be connected to convert it into a voltmeter that can read upto 2 V. Also find the resistance G of the galvanometer in terms of R_1 and R_2. **[*CBSE Delhi 2015*]**

OR

To convert a given galvanometer into a voltmeter of ranges $2V$, V and $\frac{V}{2}$ volt, resistance R_1, R_2 and R_3 ohm respectively, are required to be connected in series with the galvanometer. Obtain the relationship between R_1, R_2 and R_3. **[*CBSE 2020 (55/3/1)*]**

Ans. Let I_g be the current through galvanometer at full deflection

To measure V volts, $V = I_g (G + R_1)$ ...(*i*)

For $\frac{V}{2}$ volts, $\frac{V}{2} = I_g (G + R_2)$ ...(*ii*)

and 2 V volts, $2 V = I_g (G + R_3)$ ...(*iii*)

To measure for conversion of range dividing (*i*) by (*ii*),

$$2 = \frac{G + R_1}{G + R_2} \Rightarrow G = R_1 - 2R_2$$

Putting the value of G in (*i*), we have

$$I_g = \frac{V}{R_1 - 2R_2 + R_1} \Rightarrow I_g = \frac{V}{2R_1 - 2R_2}$$

Substituting the value of G and I_g in equation (*iii*), we have

$$2V = \frac{V}{2R_1 - 2R_2}(R_1 - 2R_2 + R_3)$$

$$4R_1 - 4R_2 = R_1 - 2R_2 + R_3$$

$$\mathbf{R_3 = 3R_1 - 2R_2}$$

Questions for Practice

1. **Choose and write the correct option in the following questions.**

(*i*) A current loop in a magnetic field

(*a*) can be in equilibrium in two orientations, both the equilibrium states are unstable.

(*b*) can be in equilibrium in two orientations, one stable while the other is unstable.

(*c*) experiences a torque whether the field is uniform or non uniform in all orientations.

(*d*) can be in equilibrium in one orientation.

(*ii*) A charge particle after being accelerated through a potential difference '*V*' enters in a uniform magnetic field and moves in a circle of radius *r*. If *V* is doubled, the radius of the circle will become **[*CBSE 2020 (55/5/1)*]**

(*a*) $2r$ (*b*) $\sqrt{2}r$

(*c*) $4r$ (*d*) $r/\sqrt{2}$

(*iii*) Two parallel conductors carrying current of 4.0 A and 10.0 A are placed 2.5 cm apart in vacuum. The force per unit length between them is **[*CBSE 2022 (55/2/4), Term-1*]**

(*a*) 6.4×10^{-5} N/m (*b*) 6.4×10^{-2} N/m

(*c*) 4.6×10^{-4} N/m (*d*) 3.2×10^{-4} N/m

(*iv*) The coil of a moving coil galvanometer is wound over a metal frame in order to **[*CBSE Sample Paper-2022, Term-1*]**

(*a*) reduce hysteresis (*b*) increase sensitivity

(*c*) increase moment of inertia (*d*) provide electromagnetic damping

(*v*) Two wires of the same length are shaped into a square of side '*a*' and a circle with radius '*r*'. If they carry same current, the ratio of their magnetic moment is [*CBSE Sample Paper-2022, Term-1*]

(*a*) $2 : \pi$ (*b*) $\pi : 2$

(*c*) $\pi : 4$ (*d*) $4 : \pi$

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

(a) ***Both A and R are true and R is the correct explanation of A.***

(b) ***Both A and R are true but R is not the correct explanation of A.***

(c) ***A is true but R is false.***

(d) ***A is false and R is also false.***

(*i*) **Assertion (*A*) :** Two parallel conducting wires carrying currents in same direction, come close to each other.

Reason (*R*) : Parallel currents attract and anti parallel currents repel.

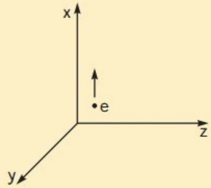
(*ii*) **Assertion (*A*) :** An electron moving along the direction of magnetic field experiences no force.

Reason (*R*) : The force on electron moving along the direction of magnetic field is

$$F = qvB \sin 0° = 0$$

3. An electron with charge $-e$ and mass m travels at a speed v in a plane perpendicular to a magnetic field of magnitude B. The electron follows a circular path of radius R. In a time t, the electron travels halfway around the circle. What is the amount of work done by the magnetic field? **[*CBSE Sample Paper 2021*]**

4. A beam of electrons projected along $+x$-axis, experiences a force due to a magnetic field along the $+y$-axis. What is the direction of the magnetic field?

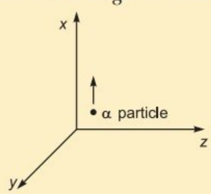


5. A horizontal overhead power line carries a current of 90 A in east to west direction. What is the magnitude and direction of the magnetic field due to the current at a distance 1.5 m below the line? **[*NCERT*]**

6. A circular coil of wire consisting of 100 turns, each of radius 8.0 cm carries a current of 0.40 A. What is the magnitude of magnetic field $\vec{B}$ at the centre of the coil? **[*NCERT*]**

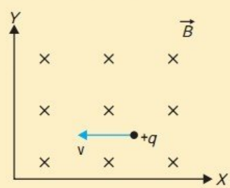
7. Two long and parallel straight wires A and B carrying currents of 8.0 A and 5.0 A in the same direction are separated by a distance of 4.0 cm. Estimate the force on a 10 cm section of wire A. **[*NCERT*]**

8. A beam of α particles projected along $+ x$-axis, experiences a force due to a magnetic field along the $+ y$-axis. What is the direction of the magnetic field? **[*CBSE (AI) 2010*]**



9. Two long and parallel straight wires carrying currents of 2 A and 5 A in the opposite directions are separated by a distance of 1 cm. Find the nature and magnitude of the magnetic force between them. **[*CBSE (F) 2011*]**

10. A point charge is moving with a constant velocity perpendicular to a uniform magnetic field as shown in the figure. What should be the magnitude and direction of the electric field so that the particle moves undeviated along the same path?



11. (*a*) Obtain the conditions under which an electron does not suffer any deflection while passing through a magnetic field.

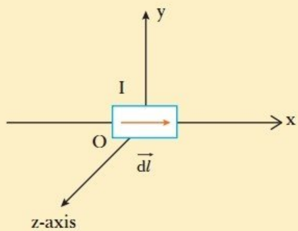
(*b*) Two protons P and Q moving with the same speed pass through the magnetic fields $\vec{B}_1$ and $\vec{B}_2$ respectively, at right angles to the field directions. If $|\vec{B}_2| > |\vec{B}_1|$, which of the two protons will describe the circular path of smaller radius? Explain. **[*CBSE 2019 (55/5/1)*]**

12. Consider the current (I) carrying circular coil placed in YZ plane with its centre at the origin. Derive expression for the value of magnetic field due to it at point $(x, 0, 0)$. *[CBSE 2020 (55/1/1)]*

13. Show that a current carrying solenoid behaves like a small bar magnet. Obtain the expression for the magnetic field at an external point lying on its axis. *[CBSE 2020 (55/4/1)]*

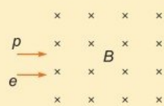
14. (*a*) Depict the magnetic field lines due to a circular current carrying loop showing the direction of field lines.

    (*b*) A current I is flowing in a conductor placed along the x-axis as shown in the figure. Find the magnitude and direction of the magnetic field due to a small current element $\vec{dl}$ lying at the origin at points (*i*) $(0, d, 0)$ and (*ii*) $(0, 0, d)$. *[CBSE 2020 (55/4/3)]*



15. A proton, a deuteron and an alpha particle, are accelerated through the same potential difference and then subjected to a uniform magnetic field $\vec{B}$, perpendicular to the direction of their motions. Compare (*i*) their kinetic energies, and (*ii*) if the radius of the circular path described by deuteron is 5 cm, determine the radii of the paths described by proton and alpha particle.

16. An electron and a proton enter a region of uniform magnetic field B with uniform speed v in a perpendicular direction (fig.).



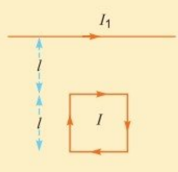
    (*i*) Show the trajectories followed by two particles.

    (*ii*) What is the ratio of the radii of the circular paths of electron to proton? *[CBSE (F) 2010]*

17. Write the expression for the magnetic moment $(\vec{M})$ due to a planar square loop of side 'l' carrying a steady current I in a vector form.

    In the given figure this loop is placed in a horizontal plane near a long straight conductor carrying a steady current I_1 at a distance l as shown. Give reasons to explain that the loop will experience a net force but no torque. Write the expression for this force acting on the loop.

    [HOTS][CBSE Delhi 2010]



18. In a chamber a uniform magnetic field of 6.5 G ($1\ G = 10^{-4}$ T) is maintained. An electron is shot into the field with a speed of $4.8 \times 10^6\ ms^{-1}$ normal to the field. Explain why the path of electron is a circle. Determine the radius of the circular orbit. ($e = 1.6 \times 10^{-19}$ C, $m = 9.1 \times 10^{-31}$ kg). **[*NCERT*]**

19. Two moving coil meters M_1 and M_2 have the following particulars:

$$R_1 = 10\ \Omega, N_1 = 30,\ A_1 = 3.6 \times 10^{-3}\ m^2,\ B_1 = 0.25\ T$$
$$R_2 = 14\ \Omega, N_2 = 42,\ A_2 = 1.8 \times 10^{-3}\ m^2,\ B_2 = 0.50\ T$$

(The spring constants are identical for the two meters).

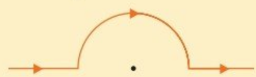
Determine the ratio of (*a*) current sensitivity and (*b*) voltage sensitivity of M_1 and M_2. **[*NCERT*]**

20. (*a*) State and explain the law used to determine magnetic field at a point due to a current element. Derive the expression for the magnetic field due to a circular current carrying loop of radius r at its centre.

(*b*) A long wire with a small current element of length 1 cm is placed at the origin and carries a current of 10 A along the *X*-axis. Find out the magnitude and direction of the magnetic field due to the element on the *Y*-axis at a distance 0.5 m from it.

21. (*a*) Derive the expression for the magnetic field due to a current carrying coil of radius r at a distance x from the centre along the *X*-axis.

(*b*) A straight wire carrying a current of 5 A is bent into a semicircular arc of radius 2 cm as shown in the figure. Find the magnitude and direction of the magnetic field at the centre of the arc.



22. A long straight wire carries a current of 35 A. What is the magnitude of magnetic field $\vec{B}$ at a point 20 cm from the wire? **[*NCERT*]**

23. (*i*) Write the principle and explain the working of a moving coil galvanometer. A galvanometer as such cannot be used to measure the current in a circuit. Why?

(*ii*) Why is the magnetic field made radial in a moving coil galvanometer? How is it achieved? **[*CBSE 2023 (55/3/1)*]**

Answers

1. (*i*) (*b*) (*ii*) (*b*) (*iii*) (*d*) (*iv*) (*d*) (*v*) (*c*)

2. (*i*) (*a*) (*ii*) (*a*)

3. Zero **5.** 1.2×10^{-5} T

6. 3.14×10^{-4} T **7.** 2×10^{-5} N **9.** 20×10^{-5} N, repulsive

15. (*i*) 1 : 1 : 2 (*ii*) $\frac{5}{\sqrt{2}}$ cm, 5 cm **18.** 4.2 cm **19.** (*a*) 1.4 (*b*) 1

20. (*b*) 4×10^{-8} T **21.** (*b*) 7.85×10^{-5} T **22.** 3.5×10^{-5} T

5 Magnetism and Matter

POINTS TO REMEMBER

1. Magnets and Magnetism

A magnet is a material that has both directive and attractive properties.

- It attracts small piece of iron, nickel, cobalt etc. This property of attraction is called magnetism.

2. Basic Properties of Magnets

(*i*) When a magnet is brought near a heap of iron fillings, the ends of magnet show the maximum attraction, These ends where the magnetic attraction is maximum, are called poles of the magnet.

- Every magnet has two poles (North and South pole).

(*ii*) When a magnet is suspended or pivoted freely, it aligns itself in the geographical north-south direction. Hence it shows directive property.

(*iii*) Unlike poles attracts and like poles repel each other.

(*iv*) Magnetic poles always exist in pairs.

(*v*) A magnet induces magnetism in a magnetic substance placed near it. This phenomenon is called magnetic induction.

3. Magnetic Dipole

An arrangement of two equal and opposite poles of bar magnet separated by a small distance is called magnetic dipole.

4. Magnetic Dipole Moment

The magnetic dipole moment is defined as the product of its pole strength and small distance between two poles (*i.e.*, magnetic length)

Mathematically,

$$\vec{m} = q_m \times 2\vec{l}$$

where q_m is the pole strength and $2\vec{l}$ is the magnetic length of the dipole measured in the direction of S to N pole.

SI unit of magntic dipole moment is ampere metre^2 (Am^2).

- The pole strength q_m is also called magnetic charge. Thus we assign magnetic charge $+q_m$ to the north poles and $-q_m$ to the south pole.
- The direction of magnetic dipole moment $\vec{m}$ is from S-pole to N-pole.

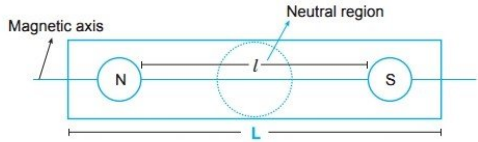
Note: When a magnet of pole strength q_m is cut into two equal parts:

(*a*) along its axis (longitudinally), the pole strength of each half becomes $q_m/2$.

(*b*) perpendicular to its axis (transversely), the pole strength of each half still remains q_m (same).

5. Magnetic length

The distance between the two poles of a magnet is called the magnetic length of the magnet.



- It is slightly less than the geometrical length of the magnet.

i.e., $$\frac{\text{Magnetic length}\,(l)}{\text{Geometrical length}\,(L)} = \frac{5}{6} = 0.84$$

6. Magnetic Field Lines

The continuous curve in a magnetic field such that the tangent at any point on it gives the direction of magnetic field at that point.

Properties of Magnetic Field Lines:

(*i*) Magnetic field lines in a magnetic field is a close and continuous curve such that the tangent drawn at any point on it shows the direction of field intensity at that point.

(*ii*) Magnetic field lines begin normally from north-pole and enter normally on south-pole.

(*iii*) Magnetic field lines tend to contract longitudinally. For this reason, two unlike poles attract each other.

(*iv*) Magnetic field lines tend to expand laterally. For this reason, two like poles repel each other.

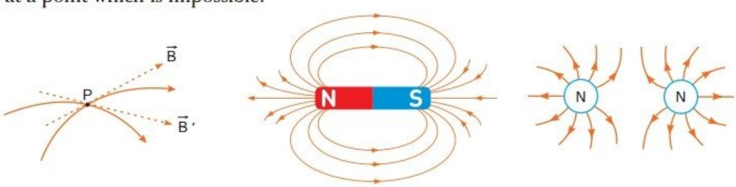
(*v*) Magnetic field lines within a magnet is directed from south-pole to north-pole. For this reason, magnetic field lies within a magnet.

(*vi*) If magnetic field lines are parallel, then the magnetic field is uniform.

(*vii*) If magnetic field lines are not parallel, then the magnetic field is not uniform.

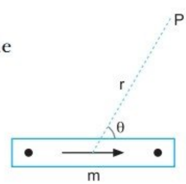
(*viii*) A stronger magnetic field is represented by more number of magnetic field lines.

(*ix*) Two magnetic field lines never intersect. If they intersect, then at the point of intersection, there will be two tangents on the two magnetic field lines showing two values of magnetic field at a point which is impossible.



7. Magnetic Field Intensity due to a Magnetic Dipole (bar Magnet)

Magnetic field intensity at a general point having polar coordinates (r, θ) due to a short magnet is given by



$$B = \frac{\mu_0}{4\pi}\frac{M}{r^3}\sqrt{1 + 3\cos^2\theta}$$

where M is the magnetic moment of the bar magnet.

Special Cases

(*i*) At axial point $\theta = 0°$,

$$B_{axis} = \frac{\mu_0}{4\pi}\frac{2M}{r^3}$$

(*ii*) At equatorial point $\theta = 90°$

$$B_{eqt.} = \frac{\mu_0}{4\pi}\frac{M}{r^3}$$

8. Gauss's law in magnetism

The net magnetic flux through any closed surface is zero. *i.e.*, $\oint \vec{B}.\vec{ds} = 0$

9. Important Terms in Magnetism

(*i*) **Magnetic permeability (μ):** It is the ability of a material to allow magnetic lines of force to pass through it and is equal to $\mu = \frac{B}{H}$, where B is the magnetic field strength and H is the magnetic field intensity.

The relative magnetic permeability $\mu_r = \frac{B}{B_0} = \frac{\mu}{\mu_0}$

where μ_0 is the permeability of free space and B_0 is the magnetic field strength in vacuum.

(*ii*) **Intensity of magnetisation (*M*):** It is defined as the magnetic moment per unit volume of a magnetised material. Its unit is Am^{-1}.

i.e., $M = \frac{m}{v}$

(*iii*) **Magnetising field intensity (*H*):** It is the magnetic field used for magnetisation of a material. If I is the current in the solenoid, then magnetising field intensity $H=nI$, where n = number of turns per metre. Its unit is Am^{-1}.

(*iv*) **Magnetic susceptibility:** It is defined as the intensity of magnetisation per unit magnetising field, *i.e.*, $\chi_m = \frac{M}{H}$

It measures the ability of a substance to take up magnetisation when placed in a magnetic field.

10. Classification of Magnetic Materials

Magnetic materials may be classified into three categories :

(*i*) **Diamagnetic substances:** These are the substances in which feeble magnetism is produced in a direction opposite to the applied magnetic field. These substances are repelled by a strong magnet. These substances have small negative values of susceptibility χ and positive low value of relative permeability μ_r, *i.e.*,

$$-1 \le \chi_m < 0 \quad \text{and} \quad 0 \le \mu_r < 1$$

The examples of diamagnetic substances are bismuth, antimony, copper, lead, water, nitrogen (at STP) and sodium chloride.

(*ii*) **Paramagnetic substances:** These are the substances in which feeble magnetism is induced in the same direction as the applied magnetic field. These are feebly attracted by a strong magnet. These substances have small positive values of M and χ and relative permeability μ_r greater than 1, *i.e.*,

$$0 < \chi_m < \varepsilon, \quad 1 < \mu_r < 1 + \varepsilon$$

where ε is a small positive number. The examples of paramagnetic substances are platinum, aluminium, calcium, manganese, oxygen (at STP) and copper chloride.

(*iii*) **Ferromagnetic substances:** These are the substances in which a strong magnetism is produced in the same direction as the applied magnetic field. These are strongly attracted by a magnet. These substances are characterised by large positive values of M and χ and values of μ_r much greater than 1, ***eg.*** Iron, cobalt, nickel and alloy like alnico.

i.e., $\chi_m >> 1, \quad \mu_r >> 1$

Distinction between Dia–, Para– and Ferromagnetics

	Property	Diamagnetic	Paramagnetic	Ferromagnetic	Remark
(*i*)	Magnetic induction B	$B < B_0$	$B > B_0$	$B >> B_0$	B_0 is magnetic induction in free space
(*ii*)	Intensity of magnetisation $M = \frac{m}{V}$	small and negative	small and positive	very high and positive	m is magnetic moment

(*iii*)	Magnetic susceptibility $\chi = \frac{M}{H}$	small and negative	small and positive	very high and positive	
(*iv*)	Relative permeability $\mu_r = \frac{\mu}{\mu_0}$	$\mu_r < 1$	$\mu_r > 1$	$\mu_r >> 1$ (of the order the thousands)	

11. Curie Law

It states that the magnetic susceptibility of paramagnetic substances is inversely proportional to absolute temperature, *i.e.*,

$$\chi_m \propto \frac{1}{T} \Rightarrow \chi = \frac{C}{T} \text{ where } C \text{ is called Curie constant}$$

12. Curie Temperature

When temperature is increased continuously, the magnetic susceptibility of ferromagnetic substances decrease and at a stage the substance changes to paramagnetic. The temperature of transition at which a ferromagnetic substance changes to paramagnetic is called Curie temperature. It is denoted by T_C. It is different for different materials. In paramagnetic phase the susceptibility is given by

$$\chi_m = \frac{C}{T - T_C}$$

Note: Diamagnetism is universal properties of all substances but it is weak in para and ferromagnetic substances and hence difficult to detect.

13. Electromagnets and Permanent Magnets

Electromagnets are made of soft iron which is characterised by low retentivity, low coercivity and high permeability. The hysteresis curve must be narrow. The energy dissipated in magnetisation and demagnetisation is consequently small.

Permanent magnets are made of steel which is characterised by high retentivity, high permeability and high coercivity.

They can retain their attractive property for a long period of time at room temperatures.

Multiple Choice Questions

Choose and write the correct option(s) in the following questions.

1. The material which is not suitable for making a permanent magnet is ***[CBSE 2020 (55/2/2)]***

(*a*) Steel (*b*) Ticonal
(*c*) Lead (*d*) Alnico

2. A magnetic needle is kept in a uniform magnetic field. It experiences

(*a*) a force and a torque (*b*) a force but not a torque
(*c*) a torque but not a force (*d*) neither a torque nor a force

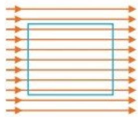
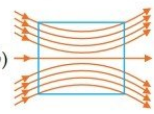
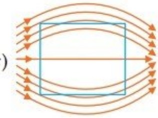
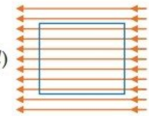
3. A magnetic needle is kept in a non-uniform magnetic field. It experiences

(*a*) a force and a torque (*b*) a force but not a torque
(c) a torque but not a force (*d*) neither a force nor a torque

4. A bar magnet of magnetic moment $\vec{m}$ is placed in a uniform magnetic field of induction $\vec{B}$. The torque exerted on it is

(*a*) $\vec{m} \cdot \vec{B}$ (*b*) $-\vec{m} \cdot \vec{B}$ (*c*) $\vec{m} \times \vec{B}$ (*d*) $-\vec{m} \times \vec{B}$

5. **A uniform magnetic field exists in space in the plane of paper and is initially directed from left to right. When a bar of soft iron is placed in the field parallel to it, the lines of force passing through it will be represented by**

(*a*)  (*b*)  (*c*)  (*d*) 

6. **Points A and B are situated perpendicular to the axis of a 2 cm long bar magnet at large distances x and $3x$ from its centre on opposite sides. The ratio of the magnetic fields at A and B will be approximately equal to**
   (*a*) 1: 9 (*b*) 2: 9 (*c*) 27: 1 (*d*) 9: 1

7. **A paramagnetic sample shows a net magnetisation of 8 Am^{-1} when placed in an external magnetic field of 0.6 T at a temperature of 4 K. When the same sample is placed in an external magnetic field of 0.2 T at a temperature of 16 K, the magnetisation will be [NCERT Exemplar]**
   (*a*) $\frac{32}{3}Am^{-1}$ (*b*) $\frac{2}{3}Am^{-1}$ (*c*) 6 Am^{-1} (*d*) 2.4 Am^{-1}

8. **A long solenoid has 1000 turns per metre and carries a current of 1 A. It has a soft iron core of $\mu_r = 1000$. The core is heated beyond the Curie temperature, T_c, then [*NCERT Exemplar*]**
   (*a*) the *H* field in the solenoid is (nearly) unchanged but the *B* field decreases drastically.
   (*b*) the *H* and *B* fields in the solenoid are nearly unchanged.
   (*c*) the magnetisation in the core reverses direction.
   (*d*) the magnetisation in the core diminishes by a factor of about 10^8.

9. **A bar magnet *AB* with magnetic moment *M* is cut into two equal parts perpendicular to its axis. One part is kept over the other so that end *B* is exactly over *A*. What will be the magnetic moment of the combination so formed?**
   (*a*) $\frac{M}{4}$ (*b*) $\frac{3M}{4}$ (*c*) M (*d*) Zero

10. **A magnet of magnetic moment *m* is cut into two equal parts. The two parts are placed perpendicular to each other so that their north poles touch each other. The resultant magnetic moment is:**
    (*a*) $\sqrt{2}\,m$ (*b*) $\frac{m}{\sqrt{2}}$ (*c*) $\sqrt{3}\,m$ (*d*) $\frac{m}{\sqrt{3}}$

11. **The meniscus of a liquid contained in one of the limbs of a narrow U-tube is placed between the pole-pieces of an electromagnet with the meniscus in a line with the field. When the electromagnet is switched on, the liquid is seen to rise in the limb. This indicates that the liquid is**
    (*a*) ferromagnetic (*b*) paramagnetic
    (*c*) diamagnetic (*d*) non-magnetic

12. **Electro-magnets are made of soft iron because soft iron has**
    (*a*) small susceptibility and small retentivity (*b*) large susceptibility and small retentivity
    (*c*) large permeability and large retentivity (*d*) small permeability and large retentivity.

13. **In a permanent magnet at room temperature [*NCERT Exemplar*]**
    (*a*) magnetic moment of each molecule is zero.
    (*b*) the individual molecules have non-zero magnetic moment which are all perfectly aligned.
    (*c*) domains are partially aligned.
    (*d*) domains are all perfectly aligned.

14. **If a magnetic substance is kept in a magnetic field, then which of the following substances is thrown out?**
    (*a*) Paramagnetic (*b*) Ferromagnetic
    (*c*) Diamegnetic (*d*) Antiferromagnetic

15. **Above Curie temperature, a** *[CBSE 2020 (55/2/1)]*
   (*a*) ferromagnetic material becomes diamagnetic.
   (*b*) ferromagnetic material becomes paramagnetic.
   (*c*) paramagnetic material becomes ferromagnetic.
   (*d*) paramagnetic material becomes diamagnetic.

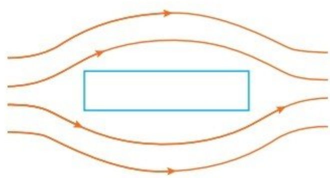
16. **In the hysteresis cycle, the value of H needed to make the intensity of magnetisation zero is called**
   (*a*) retentivity (*b*) coercive force
   (*c*) Lorentz force (*d*) none of the above

17. **Susceptibility is positive for**
   (*a*) paramagnetic substances (*b*) ferromagnetic substances
   (*c*) non-magnetic substances (*d*) diamagnetic substances

18. **A bar magnet has magnetic dipole moment $\vec{M}$. Its initial position is parallel to the direction of uniform magnetic field $\vec{B}$. In this position the magnitudes of torque and force acting on it respectively are** *[CBSE 2022 (55/2/4), Term-1]*
   (*a*) 0 and MB (*b*) MB and MB
   (*c*) 0 and 0 (*d*) $|\vec{M} \times \vec{B}|$ and 0

19. **A diamagnetic substance is brought near the north or south pole of a bar magnet. It will be**
   (*a*) repelled by both the poles. *[CBSE 2023 (55/1/1)]*
   (*b*) attracted by both the poles.
   (*c*) repelled by the north pole and attracted by the south pole.
   (*d*) attracted by the north pole and repelled by the south pole.

20. **The magnetic field lines near a substance are as shown in the figure. The substance is** *[CBSE 2023 (55/4/1)]*



   (*a*) Copper (*b*) *Iron* (*c*) Sodium (*d*) Aluminium

Answers

1. (*c*)	**2.** (*c*)	**3.** (*a*)	**4.** (*c*)	**5.** (*b*)	**6.** (*c*)	**7.** (*b*)
8. (*a*), (*d*)	**9.** (*a*)	**10.** (*b*)	**11.** (*b*)	**12.** (*b*)	**13.** (*c*)	**14.** (*c*)
15. (*b*)	**16.** (*b*)	**17.** (*a*), (*b*)	**18.** (*c*)	**19.** (*a*)	**20.** (*a*)	

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(a) *Both A and R are true and R is the correct explanation of A.*
(b) *Both A and R are true but R is not the correct explanation of A.*
(c) *A is true but R is false.*
(d) *A is false and R is also false.*

1. **Assertion (*A*) :** The susceptibility of a diamagnetic substance is independent of temperature.

   Reason (*R*) : Every atom of a diamagnetic substance is characterised by electron pairs of opposite spin; so with change of temperature, the motion of electrons are affected by same amount in opposite directions.

2. **Assertion (*A*) :** Magnetic susceptibility is a pure number.

   Reason (*R*) : The value of magnetic susceptibility for vacuum is one. [*AIIMS 2009*]

3. **Assertion (*A*) :** Soft iron is used a transformer core.

   Reason (*R*) : Soft iron has a narrow hysteresis loop.

4. **Assertion (*A*) :** Susceptibility is defined as the ratio of intensity of magnetisation I to magnetic intensity H.

   Reason (*R*) : Greater the value of susceptibility, smaller the value of intensity of magnetisation I. [*AIIMS 2018*]

5. **Assertion (*A*) :** For making permanent magnets, steel is preferred over soft iron.

   Reason (*R*) : As retentivity of steel is smaller.

6. **Assertion (*A*) :** When radius of a current carrying loop is doubled, its magnetic moment becomes four times.

   Reason (*R*) : The magnetic moment of a current carrying loop is directly proportional to the area of the loop. [*CBSE 2022 (55/2/4), Term-1*]

7. **Assertion (*A*) :** The poles of a magnet cannot be separated by breaking into two pieces.

   Reason (*R*) : The magnetic moment will be reduced to half when a magnet is broken into two equal pieces.

8. **Assertion (*A*) :** The ferromagnetic substances do not obey Curie's law.

   Reason (*R*) : At Curie point a ferromagnetic substance start behaving as a paramagnetic substance.

9. **Assertion (*A*) :** When a bar of copper is placed in an external magnetic field, the field lines get concentrated inside the bar.

   Reason (*R*) : Copper is a paramagnetic substance. [*CBSE 2023 (55/1/1)*]

10. **Assertion (*A*) :** Diamagnetic substances exhibit magnetism.

    Reason (*R*) : Diamagnetic materials do not have permanent magnetic dipole moment. [*CBSE 2023 (55/1/1)*]

Answers

1. (*a*)	**2.** (*c*)	**3.** (*a*)	**4.** (*c*)	**5.** (*b*)	**6.** (*a*)	**7.** (*b*)
8. (*b*)	**9.** (*d*)	**10.** (*b*)				

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Case-based/Passage-based Questions

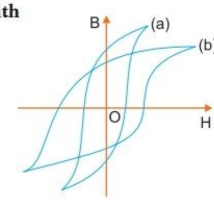
Read the paragraph given below and answer the questions that follow:

Ferromagnetism: In the absence of an external magnetic field, some of the electrons in a ferromagnetic material have their magnetic dipole moments aligned by mean of a quantum physical interaction called exchange coupling, producing regions (domains) within the material with strong magnetic dipole moments. An external field $\vec{B}_{ext}$ can align the magnetic dipole moment of those regions, producing a strong net magnetic dipole moment for the material as a whole, in the direction of $\vec{B}_{ext}$ · This net magnetic dipole moment can partially persist when field $\vec{B}_{ext}$ is removed. If $\vec{B}_{ext}$ is nonuniform, the ferromagnetic material is attracted to region of greater magnetic field. These properties are called *ferromagnetism*. Exchange coupling disappears when a sample's temperature exceeds its Curie temperature, and then the sample has only paramagnetism.

(*i*) Susceptibility is positive and small for

(*a*) paramagnetic substances
(*b*) ferromagnetic substances
(*c*) non-magnetic substances
(*d*) diamagnetic substances

(*ii*) The B—H curves (a) and (b) shown in the figure are associated with



(*a*) a diamagnetic and a paramagnetic substance respectively
(*b*) a paramagnetic and a ferromagnetic substance respectively
(*c*) soft iron and steel respectively
(*d*) steel and soft iron respectively

(*iii*) If bar magnet of pole strength m and magnetic moment M is cut equally in five parts parallel to its axis and again four equal parts perpendicular to its axis then the pole strength and magnetic moments of each piece are, respectively,

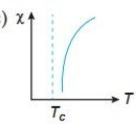
(*a*) $\frac{m}{20}, \frac{m}{20}$
(*b*) $\frac{m}{4}, \frac{M}{20}$
(*c*) $\frac{m}{5}, \frac{M}{20}$
(*d*) $\frac{m}{5}, \frac{M}{4}$

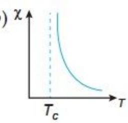
(*iv*) If the magnetizing field on a ferromagnetic material is increased, its permeability

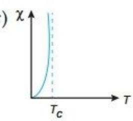
(*a*) is decreased
(*b*) is increased
(*c*) is unaffected
(*d*) may be increased or decreased

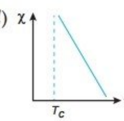
OR

The variation of magnetic susceptibility with the temperature of a ferromagnetic material can be plotted as

(*a*)


(*b*)


(*c*)


(*d*)


Explanations

(*i*) (*a*) χ is positive and small for paramagnetic materials.

(*ii*) (*c*) The retentivity of soft iron is greater than steel while coercivity of soft iron is less than steel. Hence area of (B–H) loop for soft iron is smaller than that of steel.

(*iii*) (*c*) Magnetic moment, $M = m \times 2L$ where, m = pole strength.

When it cuts in to 5 equal parts parallel to its axis, then $m' = \frac{m}{5}$.

Again, when it cuts in to 4 equal parts perpendicular to its axis. So, $2L' = \frac{2L}{4}$

Now, $M' = m' \times 2L' = \frac{m}{5} \times \frac{2L}{4} = \frac{M}{20}$

(*iv*) (*a*) We know, $\mu = \frac{B}{H} \Rightarrow \mu \propto \frac{1}{H}$

Permeability of a ferromagnetic material decreases with the increase in magnetising field intensity H.

OR

(*b*) χ of a ferromagnetic material decreases with the increase in temperature and above Curie temperature T_C, it becomes paramagnetic. Hence,

According to Curie law, $\chi \propto \frac{1}{T}$

CONCEPTUAL QUESTIONS

Q. 1. Which of the following substances are diamagnetic?

Bi, Al, Na, Cu, Ca and Ni *[CBSE Delhi 2013]*

Ans. Diamagnetic substances are (*i*) Bi (*ii*) Cu.

Q. 2. What are permanent magnets? Give one example. *[CBSE Delhi 2013]*

Ans. Substances that retain their attractive property for a long period of time at room temperature are called permanent magnets.

Examples: Those pieces which are made up of steel, Alnico, cobalt and Ticonal.

Q. 3. Mention two characteristics of a material that can be used for making permanent magnets. *[CBSE Delhi 2010]*

Ans. For making permanent magnet, the material must have high **retentivity** and high **coercivity** (*e.g.*, steel).

Q. 4. Why is the core of an electromagnet made of ferromagnetic materials? *[CBSE Delhi 2010]*

Ans. Ferromagnetic material has a high permeability. So on passing current through windings it gains sufficient magnetism immediately.

Q. 5. The permeability of a magnetic material is 0.9983. Name the type of magnetic materials it represents. *[CBSE Delhi 2011]*

Ans. μ is <1 and > 0, so magnetic material is diamagnetic.

Q. 6. A short bar magnet placed with its axis at 30° with a uniform external magnetic field of 0.25 T experiences a torque of magnitude equal to 4.5×10^{-2} N–m. What is the magnitude of magnetic moment of the magnet? *[NCERT]*

Ans. Given, $B = 0.25$ T, $\tau = 4.5 \times 10^{-2}$ N-m, $\theta = 30°$

We have $\tau = mB \sin\theta$

$$\Rightarrow \text{Magnetic moment,} \quad m = \frac{\tau}{B\sin\theta} = \frac{4.5\times10^{-2}}{0.25\times\sin 30°} = \frac{4.5\times10^{-2}}{0.25\times0.5} = \mathbf{0.36\ A\text{–}m^2}$$

Q. 7. In what way is the behaviour of a diamagnetic material different from that of a paramagnetic, when kept in an external magnetic field? *[CBSE Central 2016]*

Ans. A diamagnetic specimen would move towards the weaker region of the field while a paramagnetic specimen would move towards the stronger region.

Q. 8. The magnetic susceptibility of magnesium at 300 K is 1.2×10^5. At what temperature will its magnetic susceptibility become 1.44×10^5? *[CBSE 2019 (55/2/1)]*

Ans. From Curie law,

$$X_m \propto \frac{1}{T} \qquad ½$$

Now, $$T_2 = \frac{\chi_{m_1}}{\chi_{m_2}} \times T_1 \qquad ½$$

$$\therefore\ T_2 = \frac{1.2\times10^5}{1.44\times10^5}\times300 = \mathbf{250\ K}$$

[CBSE Marking Scheme 2019 (55/2/1)]

Q. 9. The magnetic susceptibility χ of a given material is – 0.5. Identify the magnetic material. *[CBSE 2019 (55/2/1)]*

Ans. The susceptibility of material is – 0.5, which is negative. Hence, material is diamagnetic substance.

Q. 10. Write one important property of a paramagnetic material. [CBSE 2019 (55/5/1)]

Ans. Any one property of paramagnetic materials. (e.g.)

(i) It attracts field lines, weakly.

(ii) It moves from weaker towards stronger field. or any other property.) **1**

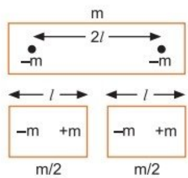
[CBSE Marking Scheme 2019 (55/5/1)]

Q. 11. Do the diamagnetic substances have resultant magnetic moment in an atom in the absence of external magnetic field? [CBSE 2019 (55/5/1)]

Ans. No, diamagnetic substances have no resultant magnetic moment in the absence of external magnetic field.

Q. 12. How does the (i) pole strength and (ii) magnetic moment of each part of a bar magnet change if it is cut into two equal pieces transverse to length?

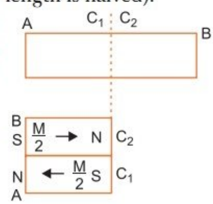
Ans. When a bar magnet of magnetic moment $(\vec{M} = m2\vec{l})$ is cut into two equal pieces transverse to its length,



(i) the pole strength remains unchanged (since pole strength depends on number of atoms in cross-sectional area).

(ii) the magnetic moment is reduced to half (since $M \propto$ length and here length is halved).

Q. 13. A hypothetical bar magnet (AB) is cut into two equal parts. One part is now kept over the other, so that the pole C_2 is above C_1. If M is the magnetic moment of the original magnet, what would be the magnetic moment of the combination, so formed?



Ans. The magnetic moment of each half bar magnet is $\frac{M}{2}$ but oppositely directed, so net magnetic moment of combination $= \frac{M}{2} - \frac{M}{2} = 0$ (zero).

Very Short Answer Questions

Each of the following questions are of 2 marks.

Q. 1. Write any two points of difference between a diamagnetic and a paramagnetic substance. [CBSE 2023 (55/3/1)]

Ans.

Diamagnetic Substance	Paramagnetic
(i) They are feebly reppeled by magnets	(i) They are feebly attracted by magnet
(ii) Susceptibility is independent of temperature.	(ii) Susceptibility varies inversely with temperature. i.e., $X_m \propto \frac{1}{T}$
(iii) $-1 \leq \chi < 0$ and $0 \leq \mu_r < 1$	(iii) $0 < \chi < \varepsilon$ and $1 \leq \mu_r < (1+\varepsilon)$

[any two]

Q. 2. The susceptibility of a magnetic material is -2.6×10^{-5}. Identify the type of magnetic material and state its two properties. *[CBSE Delhi 2012]*

Ans. The magnetic material having negative susceptibility is diamagnetic in nature.

Properties:

(*i*) This material has + ve but low relative permeability.

(*ii*) They have the tendency to move from stronger to weaker part of the external magnetic field.

Q. 3. (*a*) Closely wound solenoid of 800 turns and area of cross-section 2.5×10^{-4} m^2 carries a current of 3.0 A. Explain the sense in which solenoid acts like a bar magnet. What is the associated magnetic moment?

(*b*) If the solenoid is free to turn about the vertical direction in an external uniform horizontal magnetic field at 0.25 T, what is the magnitude of the torque on the solenoid when its axis makes an angle of 30° with the direction of the external field. *[NCERT]*

Ans. (*a*) If solenoid is suspended freely, it stays in N-S direction. The polarity of solenoid depends on the sense of flow of current. If to an observer looking towards an end of a solenoid, the current appears anticlockwise, the end of solenoid will be N-pole and other end will be S-pole.

Magnetic moment, $m = NIA = 800 \times 3.0 \times 2.5 \times 10^{-4} = \mathbf{0.60\ A\text{-}m^2}$

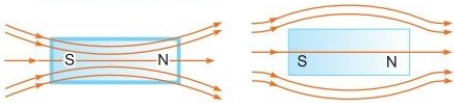
(*b*) Torque on solenoid $\tau = mB \sin\theta$

$$= 0.60 \times 0.25 \sin 30°$$

$$= 0.60 \times 0.25 \times 0.5 = \mathbf{7.5 \times 10^{-2}\ N\text{–}m}$$

Q. 4. Two identical bars, one of paramagnetic material and other of diamagnetic material are kept in a uniform external magnetic field parallel to it. Draw diagrammatically the modifications in the magnetic field pattern in each case. *[CBSE 2020 (55/3/1)]*

Ans.



Paramagnetic substance (i)

Diamagnetic substance (ii)

- A paramagnetic material tends to move from weaker field to stronger field regions of the magnetic field. So, the number of lines of magnetic field increases when passing through it.
- A diamagnetic material tends to move from stronger field to weaker field region of the magnetic field. So, the number of lines of magnetic field passing through it decreases.

Q. 5. Write two properties of a material suitable for making (*a*) a permanent magnet, and (*b*) an electromagnet. *[CBSE (AI) 2017]*

Ans.

6. Making a permanent magnet

Usually steel is used for making the permanent magnet. Because the material used

should require high retentivity

high coercivity

intensive magnetism

For making electromagnets:

Soft iron core is mainly used for making an electromagnet because of the following properties:

high permeability

less area of the covered hysteresis loop

in order to minimise the energy loss

High retentivity
Low coercivity
Mainly the relative permeability of the material should be very high in order to permit more magnetic field lines to pass through them

[*Topper's Answer 2017*]

Q. 6. What is the basic difference between the atom and molecule of a diamagnetic and a paramagnetic material? Why are elements with even atomic number more likely to be diamagnetic?

Ans. Atoms/molecules of a diamagnetic substance contain even number of electrons and these electrons form the pairs of opposite spin; while the atoms/molecules of a paramagnetic substance have excess of electrons spinning in the same direction.

The elements with even atomic number Z has even number of electrons in its atoms/molecules, so they are more likely to form electrons pairs of opposite spin and hence more likely to be diamagnetic.

Q. 7. A small magnetised needle *P* is placed at the origin of *x–y* plane with its magnetic moment pointing along the *y*-axis. Another identical magnetised needle *Q* is placed in two positions, on by one. [*CBSE 2023 (55/4/1)*]

***Case 1* : at (*a*, 0) with its magnetic moment pointing along *x*-axis.**

***Case 2* : at (*a*, 0) with its magnetic moment pointing along *y*-axis.**

(*a*) In which case is the potential energy of *P* and *Q* minimum?

(*b*) In which case is *P* and *Q* not in equilibrium?

Justify your answers.

Ans. (*a*) Since $P.E = U = -MB\cos\theta$

Case 1: $\theta = 90° \Rightarrow U = 0$

Case 2: $\theta = 0° \Rightarrow U = -MB$

Hence, *P.E* is minimum in case 2.

(*b*) Since $\tau = MB\sin\theta$

Case 1: $\theta = 90° \Rightarrow \tau = MB$

Case 2: $\theta = 0° \Rightarrow \tau = 0$

Hence, *P* and *Q* are not in equilibrium in case 1. In this case, *Q* is at normal bisector of *P*.

Short Answer Questions

Each of the following questions are of 3 marks.

Q. 1. (*i*) Mention two properties of soft iron due to which it is preferred for making an electromagnet.

(*ii*) State Gauss's law in magnetism. How is it different from Gauss's law in electrostatics and why? [*CBSE South 2016*]

Ans. (*i*) Low coercivity and high permeability

(*ii*) **Gauss's Law in magnetism:** The net magnetic flux through any closed surface is zero.

$$\oint B.ds = 0$$

Gauss's Law in electrostatics: The net electric flux through any closed surface is $\frac{1}{\varepsilon_0}$ times the net charge enclosed by the surface.

$$\oint E.ds = \frac{q}{\varepsilon_0}$$

The difference between the Gauss's law of magnetism and that for electrostatic is a reflection of the fact that magnetic monopole do not exist *i.e.*, magnetic poles always exist in pairs.

Q. 2. A bar magnet of magnetic moment 1.5 JT^{-1} lies aligned with the direction of a uniform magnetic field of 0.22 T.

(a) What is the amount of work required by an external torque to turn the magnet so as to align its magnetic moment

(i) normal to the field direction? and (ii) opposite to the field direction?

(b) What is the torque on the magnet in cases (i) and (ii)? **[NCERT]**

Ans. (a) Work done in aligning a magnet from orientation θ_1 to θ_2 is given by

$$W = U_2 - U_1 = -mB\cos\theta_2 - (-mB\cos\theta_1)$$
$$= -mB(\cos\theta_2 - \cos\theta_1)$$

(i) Here $\theta_1 = 0°, \theta_2 = 90°$

$\therefore \quad W = mB(\cos 0° - \cos 90°) = mB(1-0) = mB$

$= 1.5 \times 0.22 = \mathbf{0.33\ J}$

(ii) Here $\theta_1 = 0°, \theta_2 = 180°$

$\therefore \quad W = mB(\cos 0° - \cos 180°) = 2mB$

$= 2 \times 1.5 \times 0.22 = \mathbf{0.66\ J}$

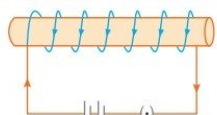
(b) Torque $\tau = mB\sin\theta$

In (i) $\theta = 90°, \tau = mB\sin 90° = mB = 1.5 \times 0.22 = \mathbf{0.33\ N\text{-}m}$

This torque tends to align the magnet along the direction of field direction.

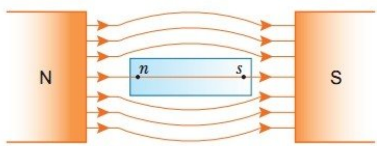
In (ii) $\theta = 180°, \tau = mB\sin 180° = \mathbf{0}$

Q. 3. Draw the magnetic field lines for a current carrying solenoid when a rod made of (a) copper, (b) aluminium and (c) iron are inserted within the solenoid as shown.

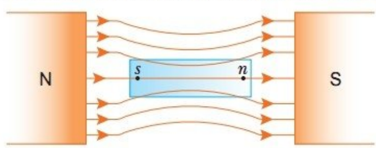


[CBSE Sample Paper 2018]

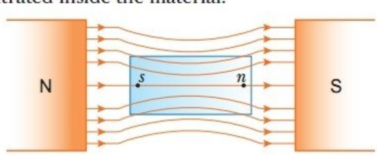
Ans. (a) When a bar of diamagnetic material (copper) is placed in an external magnetic field, the field lines are repelled or expelled and the field inside the material is reduced.



(b) When a bar of paramagnetic material (Aluminium) is placed in an external field, the field lines gets concentrated inside the material and the field inside is enhanced.



(c) When a ferromagnetic material (Iron) is placed in an internal magnetic field, the field lines are highly concentrated inside the material.



Q. 4. In what way is Gauss's law in magnetism different from that used in electrostatics? Explain briefly. The Earth's magnetic field at the equator is approximately 0.4 G. Estimate the Earth's magnetic dipole moment. Given: Radius of the Earth = 6400 km. **[*CBSE Patna 2015*]**

Ans. As we know that

Isolated positive or negative charge exists freely. So, Gauss's law states that $\oint \vec{E} \cdot d\vec{S} = \frac{1}{\varepsilon_0}[q]$

Isolated magnetic poles do not exist. So, Gauss's law states that

$$\oint \vec{B} \cdot \vec{dS} = 0$$

Magnetic field intensity at the equator is

$$B = \frac{\mu_0}{4\pi} \cdot \frac{m}{R^3} = 10^{-7} \frac{m}{R^3}$$

$$\therefore \quad m = 10^7 \cdot BR^3$$

$$= 10^7 \times 0.4 \times 10^{-4} \times (6400 \times 10^3)^3$$

$$= \mathbf{1.05 \times 10^{23}\ Am^2}$$

Q. 5. A bar magnet of magnetic moment 6 J/T is aligned at 60° with a uniform external magnetic field of 0·44 T. Calculate (*a*) the work done in turning the magnet to align its magnetic moment (*i*) normal to the magnetic field, (*ii*) opposite to the magnetic field, and (*b*) the torque on the magnet in the final orientation in case (*ii*). **[*CBSE Examination Paper 2018*]**

Ans. (*a*) Work done $= mB(\cos\theta_1 - \cos\theta_2)$

(*i*) $\theta_1 = 60°, \theta_2 = 90°$

$\therefore$ Work done $= mB(\cos 60° - \cos 90°)$

$$= mB\left(\frac{1}{2} - 0\right) = \frac{1}{2} mB$$

$$= \frac{1}{2} \times 6 \times 0.44 \text{ J} = \mathbf{1.32\ J}$$

(*ii*) $\theta_1 = 60°, \theta_2 = 180°$

$\therefore$ Work done $= mB(\cos 60° - \cos 180°)$

$$= mB\left(\frac{1}{2} - (-1)\right) = \frac{3}{2} mB$$

$$= \frac{3}{2} \times 6 \times 0.44 \text{ J} = \mathbf{3.96\ J}$$

(*b*) Torque $= |\vec{m} \times \vec{B}| = mB\sin\theta$

For $\theta = 180°$ and $B = 0.44$ T we have

Torque $= 6 \times 0.44 \sin 180° = \mathbf{0}$

Q. 6. (*a*) An iron ring of relative permeability μ_r has windings of insulated copper wire of *n* turns per metre. When the current in the windings is *I*, find the expression for the magnetic field in the ring.

(*b*) The susceptibility of a magnetic material is 0.9853. Identify the type of magnetic material. Draw the modification of the field pattern on keeping a piece of this material in a uniform magnetic field. **[*CBSE Examination Paper 2019*]**

Ans. (*a*) From Ampere's circuital law, we have,

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 \mu_r I_{enclosed} \qquad ...(i)$$

For the field inside the ring, we can write

$$\oint \vec{B} \cdot \vec{dl} = \oint Bdl = B.2\pi r \quad (r = \text{radius of the ring})$$

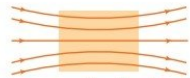
Also, $I_{enclosed} = (2\pi rn)I$

$\therefore \quad B.2\pi r = \mu_0 \mu_r.(n.2\pi r)I \qquad$ [Using equation (*i*)]

$\therefore B = \mu_0 \mu_r .nI$

(*b*) The material is paramagnetic.

The field pattern gets modified as shown in the figure alongside.



Q. 7. (*a*) Show that the time period (*T*) of oscillations of a freely suspended magnetic dipole of magnetic moment (*m*) in a uniform magnetic field (*B*) is given by $T = 2\pi\sqrt{\frac{I}{mB}}$, where *I* is a moment of inertia of the magnetic dipole.

(*b*) Identify the following magnetic materials:

(*i*) A material having susceptibility $(\chi_m) = -0.00015$

(*ii*) A material having susceptibility $(\chi_m) = 10^{-5}$ **[*CBSE 2019 (55/3/1)*]**

Ans. (*a*) Let us consider a uniform magnetic field $\vec{B}$ exists in the region, in which a magnet of dipole moment $\vec{m}$ is placed. The dipole is making small angle θ with the magnetic field. The torque acts on the magnet is given by

$$\vec{\tau} = -mB \sin\theta \qquad \text{(Restoring torque)}$$
$$= -mB\,\theta \qquad (\because \theta \text{ in small})$$

Also the torque on dipole try to restore its initial position *i.e.*, along the direction of magnetic field. (I = moment of inertia)

In equilibrium

$$I\frac{d^2\theta}{dt^2} = -mB\sin\theta$$

Negative sign implies that restoring torque is in opposition to deflecting torque.

$$\frac{d^2\theta}{dt^2} = \frac{-mB}{I}\theta$$

Comparing with equation of angular SHM

$$\frac{d^2\theta}{dt^2} = -\omega^2\theta$$

We have

$$\omega^2 = \frac{mB}{I} \Rightarrow \omega = \sqrt{\frac{mB}{I}}$$

$$\Rightarrow \qquad \frac{2\pi}{T} = \sqrt{\frac{mB}{I}} \Rightarrow \frac{T}{2\pi} = \sqrt{\frac{I}{mB}}$$

$$T = 2\pi\sqrt{\frac{I}{mB}}$$

(*b*) (*i*) Diamagnetic substance. (*ii*) Paramagnetic substance.

Q. 8. Write three points of differences between para-, dia- and ferro- magnetic materials, giving one example for each. **[*CBSE 2019 (55/1/1)*]**

Ans.

	Diamagnetic	Paramagnetic	Ferromagnetic	
1.	$-1 \le \chi \langle 0$	$-0 < \chi \langle \varepsilon$	$\chi \rangle\rangle 1$	½
2.	$0 \le \mu_r \langle 1$	$1 \le \mu_r \langle (1+\varepsilon)$	$\mu_r \rangle\rangle 1$	½
3.	$\mu \langle \mu_0$	$\mu \rangle\rangle \mu_0$	$\mu \rangle\rangle \mu_0$	½

Where ε is any positive constant.

[**Note:** Give full credit of this part if student write any other three correct difference]

Examples (Any one example of each type)

Diamagnetic materials: Bi, Cu, Pb, Si, water, NaCI, Nitrogen (at STP) ½

Paramagnetic materials: Al, Na, Ca, Oxygen (at STP), Copper chloride ½

Ferromagnetic materials: Fe, Ni, Co, AlniCo ½

[*CBSE Marking Scheme 2019 (55/1/1)*]

Q. 9. **(a) State Gauss's law for magnetism. Explain its significance.** *[CBSE 2019 (55/1/1)]*

(b) Write the four important properties of the magnetic field lines due to a bar magnet.

Ans. (a) Gauss's law for magnetism states that "The total flux of the magnetic field, through any closed surface, is always zero. ½

Alternatively,

$$\Rightarrow \oint \vec{B}.\vec{d}s = 0$$

This law implies that magnetic monopoles do not exist" / magnetic field lines form closed loops ½

[Note: Award this 1 mark if the student just attempts it]

(b) Four properties of magnetic field lines

(i) Magnetic field lines always form continuous closed loops. ½

(ii) The tangent to the magnetic field line at a given point represents the direction of the net magnetic field at that point. ½

(iii) The larger is the number of field lines crossing per unit area, the stronger is the magnitude of the magnetic field. ½

(iv) Magnetic field lines do not intersect. ½

[CBSE Marking Scheme 2019 (55/1/1)]

Long Answer Questions

Each of the following questions are of 5 marks.

Q. 1. Derive an expression for magnetic field intensity due to a magnetic dipole of a bar magnet at a point on its axial line.

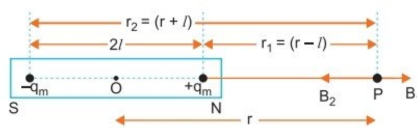
Ans. Consider a magnetic dipole (or a bar magnet) SN of length $2l$ having south pole at S and north pole at N. The strength of south and north poles are $-q_m$ and $+q_m$ respectively.

Magnetic moment of magnetic dipole $m = q_m 2l$, its direction is from S to N.

Consider a point P on the axis of magnetic dipole at a distance r from mid point O of dipole.

The distance of point P from N-pole, $r_1 = (r - l)$

The distance of point P from S-pole, $r_2 = (r + l)$



Let B_1 and B_2 be the magnetic field intensities at point P due to north and south poles respectively. The directions of magnetic field due to north pole is away from N-pole and due to south pole is towards the S-pole. Therefore,

$$B_1 = \frac{\mu_0}{4\pi}\frac{q_m}{(r-l)^2} \text{ from } N \text{ to } P \text{ and } B_2 = \frac{\mu_0}{4\pi}\frac{q_m}{(r+l)^2} \text{ from } P \text{ to } S$$

Clearly, the directions of magnetic field strengths $\vec{B}_1$ and $\vec{B}_2$ are along the same line but opposite to each other and $B_1 > B_2$.

Therefore, the resultant magnetic field intensity due to bar magnet has magnitude equal to the difference of B_1 and B_2 and direction from N to P.

i.e.,
$$B = B_1 - B_2 = \frac{\mu_0}{4\pi}\frac{q_m}{(r-l)^2} - \frac{\mu_0}{4\pi}\frac{q_m}{(r+l)^2}$$

$$= \frac{\mu_0}{4\pi}q_m\left[\frac{1}{(r-l)^2} - \frac{1}{(r+l)^2}\right] = \frac{\mu_0}{4\pi}q_m\left[\frac{(r+l)^2-(r-l)^2}{(r^2-l^2)^2}\right]$$

$$= \frac{\mu_0}{4\pi} q_m \left[\frac{4rl}{(r^2 - l^2)^2}\right] = \frac{\mu_0}{4\pi} \frac{2(q_m 2l)r}{(r^2 - l^2)^2}$$

But $q_m\, 2l = m$ (magnetic dipole moment)

$$\therefore \qquad B = \frac{\mu_0}{4\pi} \frac{2m.r}{(r^2 - l^2)^2} \qquad \ldots(i)$$

If the bar magnet is very short and point P is far away from the magnet, the $r >> l$, therefore, equation (i) takes the form

$$B = \frac{\mu_0}{4\pi} \frac{2mr}{r^4}$$

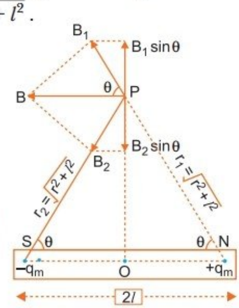
or

$$B = \frac{\mu_0}{4\pi} \frac{2m}{r^3}$$

This is the expression for magnetic field intensity at axial position due to a short bar magnet.

Q. 2. Derive an expression for magnetic field intensity due to a magnetic dipole of a bar magnet at a point lies on its equatorial line.

Ans. Consider a point P on equatorial position (or broad side on position) of short bar magnet of length $2l$, having north pole (N) and south pole (S) of strength $+q_m$ and $-q_m$ respectively. The distance of point P from the mid point (O) of magnet is r. Let B_1 and B_2 be the magnetic field intensities due to north and south poles respectively. $NP = SP = \sqrt{r^2 + l^2}$.



$$\vec{B}_1 = \frac{\mu_0}{4\pi} \frac{q_m}{r^2 + l^2} \text{ along } N \text{ to } P$$

$$\vec{B}_2 = \frac{\mu_0}{4\pi} \frac{q_m}{r^2 + l^2} \text{ along } P \text{ to } S$$

Clearly, magnitudes of $\vec{B}_1$ and $\vec{B}_2$ are equal

i.e., $\quad |\vec{B}_1| = |\vec{B}_2| \quad$ or $\quad B_1 = B_2$

To find the resultant of $\vec{B}_1$ and $\vec{B}_2$, we resolve them along and perpendicular to magnetic axis SN. Components of $\vec{B}_1$ along and perpendicular to magnetic axis are $B_1 \cos\theta$ and $B_2 \sin\theta$ respectively. Components of $\vec{B}_2$ along and perpendicular to magnetic axis are $B_2 \cos\theta$ and $B_2 \sin\theta$ respectively. Clearly, components of $\vec{B}_1$ and $\vec{B}_2$ perpendicular to axis SN. $B_1 \sin\theta$ and $B_2 \sin\theta$ are equal in magnitude and opposite in direction and hence, cancel each other; while the components of $\vec{B}_1$ and $\vec{B}_2$ along the axis are in the same direction and hence, add up to give to resultant magnetic field parallel to the direction $\overrightarrow{NS}$.

$\therefore$ Resultant magnetic field intensity at P.

$$B = B_1 \cos\theta + B_2 \cos\theta$$

But $\quad B_1 = B_2 = \frac{\mu_0}{4\pi} \frac{q_m}{r^2 + l^2}$ and $\cos\theta = \frac{ON}{PN} = \frac{l}{\sqrt{r^2 + l^2}} = \frac{l}{(r^2 + l^2)^{1/2}}$

$$\therefore \qquad B = 2B_1 \cos\theta = 2 \times \frac{\mu_0}{4\pi} \frac{q_m}{(r^2 + l^2)} \times \frac{l}{(r^2 + l^2)^{1/2}} = \frac{\mu_0}{4\pi} \frac{2q_m l}{(r^2 + l^2)^{3/2}}$$

But $q_m . 2l = m$, magnetic moment of magnet

$$\therefore \qquad B = \frac{\mu_0}{4\pi} \frac{m}{(r^2 + l^2)^{3/2}} \qquad \ldots(i)$$

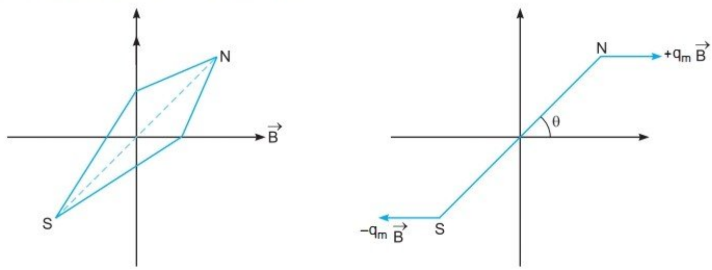
If the magnet is very short and point P is far away, we have $l << r$; so l^2 may be neglected as compared to r^2 and so equation (i) takes the form

$$B = \frac{\mu_0}{4\pi} \frac{m}{r^3}$$

This is expression for magnetic field intensity at equatorial position of the magnet.

Q. 3. A small compass needle of magnetic moment 'm' is free to turn about an axis perpendicular to the direction of uniform magnetic field 'B'. The moment of inertia of the needle about the axis is 'I'. The needle is slightly disturbed from its stable position and then released. Prove that it executes simple harmonic motion. Hence deduce the expression for its time period.

Ans. If magnetic compass of dipole moment $\vec{m}$ is placed at angle θ in uniform magnetic field, and released it experiences a restoring torque.



Restoring torque, $\vec{\tau} = -$ magnetic force × perpendicular distance

$$= -q_m B \cdot (2a \sin\theta),$$

$$\tau = -mB.\sin\theta, \text{ where } q_m = \text{pole strength}, m = q_m.2a \text{ (magnetic moment)}$$

Negative sign shows that restoring torque acts in the opposite direction to that of defecting torque.

In equilibrium, the equation of motion,

$$\Rightarrow \quad I\frac{d^2\theta}{dt^2} = -mB\theta \qquad \text{(For small angle } \sin\theta \approx \theta\text{)}$$

$$\Rightarrow \quad \frac{d^2\theta}{dt^2} = -\frac{mB}{I}\theta \quad \Rightarrow \quad \frac{d^2\theta}{dt^2} = -\left(\frac{mB}{I}\right)\theta$$

Since $\dfrac{d^2\theta}{dt^2} \propto \theta \Rightarrow \dfrac{d^2\theta}{dt^2} = -\omega^2\theta$

It represents the simple harmonic motion with angular frequency

$$\omega^2 = \frac{mB}{I} \Rightarrow T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{I}{mB}}$$

Questions for Practice

1. **Choose and write the correct option in the following questions.**
   (*i*) If a diamagnetic substance is brought near the north or the south pole of a bar magnet, it is
   (*a*) repelled by the north pole and attracted by the south pole
   (*b*) attracted by the north pole and repelled by the south pole
   (*c*) attracted by both the poles
   (*d*) repelled by both the poles
   (*ii*) A bar magnet having a magnetic moment of 2×10^4 J T^{-1} is free to rotate in a horizontal plane. A horizontal magnetic field $B = 6 \times 10^{-4}$ T exists in the space. The work done in taking the magnet slowly from a direction parallel to the field to a direction 60° from the field is
   (*a*) 12 J (*b*) 6 J
   (*c*) 2 J (*d*) 0.6 J

(*iii*) Above Curie's temperature ferromagnetic substances becomes

(*a*) paramagnetic (*b*) diamagnetic

(*c*) superconductor (*d*) no change

(*iv*) There are four light-weight-rod samples, A, B, C, and D separately suspended by threads. A bar magnet is slowly brought near each sample and the following observation are noted

(*i*) A is feebly repelled (*ii*) B is feebly attracted

(*iii*) C is strongly attracted (*iv*) D remains unaffected

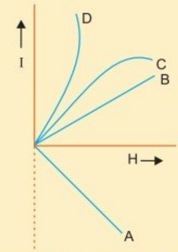
Which one of the following is true?

(*a*) A is of non-magnetic material

(*b*) B is of a paramagnetic material

(*c*) C is of a diamagnetic material

(*d*) D is of a ferromagnetic material



(*v*) The most appropriate I-H curve for a paramagnetic substance shown in figure is

(*a*) A (*b*) B

(*c*) C (*d*) D

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

(**a**) ***Both A and R are true and R is the correct explanation of A.***

(**b**) ***Both A and R are true but R is not the correct explanation of A.***

(**c**) ***A is true but R is false.***

(**d**) ***A is false and R is also false.***

(***i***) **Assertion (*A*) :** Diamagnetic materials can exhibit magnetism.

Reason (*R*) : Diamagnetic materials have permanent magnetic dipole moment.

(***ii***) **Assertion (*A*) :** The poles of a bar magnet cannot be separated.

Reason (*R*) : Magnetic monopoles do not exist. ***[CBSE 2022 (55/2/4), Term–1]***

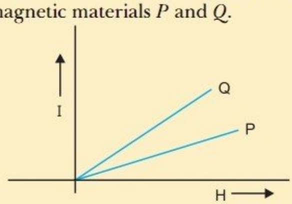
3. Define magnetic length of a barmagnet. Also find the ratio of magnetic length and geometrical length of bar magnet.

4. The susceptibility of a magnetic material is 1.9×10^{-5}. Name the type of magnetic materials it represents.

5. Depict the behaviour of magnetic field lines in the presence of a diamagnetic material.

6. The susceptibility of a magnetic materials is -4.2×10^{-6}. Name the type of magnetic materials it represents. ***[CBSE 2011]***

7. The given graph shows the variation of intensity of magnetisation I with strength of applied magnetic field H for two magnetic materials P and Q.



(*i*) Identify the materials P and Q.

(*ii*) For material P, plot the variation of intensity of magnetisation with temperature. Justify your answer.

8. The relative magnetic permeability of a magnetic material is 800. Identify the nature of magnetic material and state its two properties.

9. From molecular view point, discuss the temperature dependence of susceptibility for diamagnetism, paramagnetism and ferromagnetism.

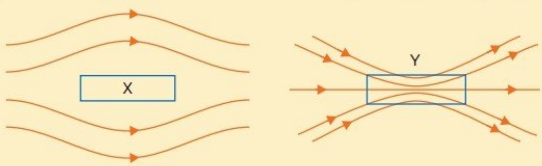
10. A short bar magnet of magnetic moment $m = 0.32\ JT^{-1}$ is placed in a uniform magnetic field of 0.15 T. If the bar is free to rotate in the plane of the field, which orientation would correspond to its (*i*) stable and (*ii*) unstable equilibrium? What is the potential energy of the magnet in each case? **[*NCERT*]**

11. A short bar magnet has a magnetic moment of $0.48\ JT^{-1}$. Give the magnitude and direction of the magnetic field produced by the magnet at a distance of 10 cm from the centre of magnet on (*a*) the axis, (*b*) equatorial lines (normal bisector) of the magnet. **[*NCERT*]**

12. Explain the following:
    (*i*) Why do magnetic field lines form continuous closed loops?
    (*ii*) Why are the field lines repelled (expelled) when a diamagnetic material is placed in an external uniform magnetic field? **[*CBSE (F) 2011*]**

13. A uniform conducting wire of length $12a$ and resistance R is wound up as a current carrying coil in the shape of (*i*) an equilateral triangle of side a; (*ii*) a square of sides a and, (*iii*) a regular hexagon of sides a. The coil is connected to a voltage source V_0. Find the magnetic moment of the coils in each case.

14. A uniform magnetic field gets modified as shown below when two specimens X and Y are placed in it. Identify whether specimens X and Y are diamagnetic, paramagnetic or ferromagnetic.



15. A closely wound solenoid of 2000 turns and area of cross-section $1.6 \times 10^{-4}\ m^2$, carrying a current of 4.0 A is suspended through its centre allowing it to turn in a horizontal plane.
    (*a*) What is the magnetic moment associated with the solenoid?
    (*b*) What are the force and torque on the solenoid if a uniform magnetic field of 7.5×10^{-2} T is set up at an angle of 30° with the axis of the solenoid? **[*NCERT*]**

16. (*a*) Draw the magnetic field lines due to a circular loop of area A carrying current I. Show that it acts as a bar magnet of magnetic moment $\vec{m} = \vec{IA}$.
    (*b*) Derive the expression for the magnetic field due to a solenoid of length '$2l$', radius 'a' having 'n' number of turns per unit length and carrying a steady current 'I' at a point on the axial line, distant 'r' from the centre of the solenoid. How does this expression compare with the axial magnetic field due to a bar magnet of magnetic moment 'm'?

Answers

1. (*i*) (*d*) (*ii*) (*b*) (*iii*) (*a*) (*iv*) (*b*) (*v*) (*b*)

2. (*i*) (*c*) (*ii*) (*a*)

10. (*i*) -4.8×10^{-2} J (*ii*) $+4.8 \times 10^{-2}$ J **11.** (*a*) 0.96 G (*b*) 0.48 G

13. (*i*) $\sqrt{3}\, a^2 I$ (*ii*) $3a^2 I$ (*iii*) $3\sqrt{3}\, a^2 I$ **15.** (*a*) 1.28 Am^2 (*b*) Zero, 4.8×10^{-2} Nm.

6 Electromagnetic Induction

POINTS TO REMEMBER

1. Electromagnetic Induction

The phenomenon of generation of induced emf and induced current due to change in magnetic field lines associated with a closed circuit is called electromagnetic induction.

2. Magnetic Flux

Magnetic flux through a surface of area A placed in a uniform magnetic field is $\phi_m = \vec{B}.\vec{A} = BA\cos\theta$, θ being angle between $\vec{B}$ and normal to $\vec{A}$. If magnetic field is not uniform, then $\phi_m = \int_A \vec{B}.d\vec{A}$, where integral extends for whole area A.

The SI unit of magnetic flux is weber. Magnetic flux is a scalar quantity; because of being scalar product of two vectors $\vec{B}$ and $\vec{A}$.

3. Faraday's Laws of Electromagnetic Induction

(*i*) Whenever there is a change in magnetic flux linked with a coil, an emf is induced in the coil. The induced emf is proportional to the rate of change of magnetic flux linked with the coil.

i.e., $\varepsilon \propto \dfrac{\Delta\phi}{\Delta t}$

(*ii*) emf induced in the coil opposes the change in flux, *i.e.*,

$$\varepsilon \propto -\frac{\Delta\phi}{\Delta t} \Rightarrow \varepsilon = -k\frac{\Delta\phi}{\Delta t}$$

where k is a constant of proportionality.

Negative sign represents opposition to change in flux.

In SI system ϕ is in weber, t in second, ε in volt, when $k = 1, \varepsilon = -\dfrac{\Delta\phi}{\Delta t}$

If the coil has N-turns, then $\varepsilon = -N\dfrac{\Delta\phi}{\Delta t}$

4. Induced Current and Induced Charge

If a coil is closed and has resistance R, then current induced in the coil,

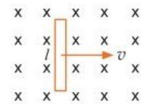
$$I = \frac{\varepsilon}{R} = -\frac{N}{R}\frac{\Delta\phi}{\Delta t}$$

Induced charge, $q = I\,\Delta t = -\dfrac{N\Delta\phi}{R} = \dfrac{\text{Total flux linkage}}{\text{Resistance}}$

5. Lenz's Law

It states that the direction of induced emf is such that it tends to produce a current which opposes the change in magnetic flux producing it.

6. EMF Induced in a Moving Conducting Rod



EMF induced in a conducting rod of length l moving with velocity v in a magnetic field of induction B, such that B, l and v are mutually perpendicular, is given by

$$\varepsilon = Bvl$$

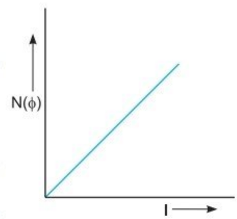
force required to keep the rod in constant motion is $F = BIL = \dfrac{B^2 l^2 v}{r}$

7. Self Induction

When the current in a coil is changed, an induced emf is produced in the same coil. This phenomenon is called self-induction. If L is self-inductance of coil, then

$$N\phi \propto I \text{ or } N\phi = LI \Rightarrow L = \frac{N\phi}{I}$$

L is also called coefficient of self induction.



The graph between effective magnetic flux (Nϕ) and current I is straight line of slope self inductance L.

Also induced emf $\varepsilon = -L\dfrac{\Delta I}{\Delta t}$

The unit of self inductance is henry (H). The self induction acts as inertia in electrical circuits; so it is also called electrical inertia.

The self inductance of a solenoid consisting core of relative permeability μ_r is $L = \mu_r \mu_0 n^2 Al$

where $n = \dfrac{N}{l}$ is the number of turns per metre length.

8. Mutual Induction

When two coils are placed nearby and the current in one coil (often called primary coil) is changed, the magnetic flux linked with the neighbouring coil (often called secondary coil) changes; due to which an emf is induced in the neighbouring coil. This effect is called the mutual induction. If M is mutual inductance of two coils, then $\phi_2 \propto I_1$ or $\phi_2 = MI_1$

Definition of mutual inductance: $M = \dfrac{\phi_2}{I_1}$.

The mutual inductance of two coils is defined as the magnetic flux linked with the secondary coil when the current in primary coil is 1 ampere.

Also induced emf in secondary coil $\varepsilon_2 = -M\dfrac{\Delta I_1}{\Delta t} \Rightarrow M = -\dfrac{\varepsilon_2}{\Delta I_1/\Delta t}$.

The mutual inductance of two coils is defined as the emf induced in the secondary coil when the rate of change of current in the primary coil is 1 A/s.

The SI unit of mutual inductance is also henry (H). The mutual inductance of two coils does not depend on the fact which coil carries the current and in which coil emf is induced *i.e.*, $M_{12} = M_{21} = M$

This is also called reciprocity theorem of mutual inductance.

If L_1 and L_2 are self-inductances of two coils with 100% flux linkage between them, then

$M = \sqrt{L_1 L_2}$, otherwise $M = k\sqrt{L_1 L_2}$, where k is coefficient of flux linkage between the coils.

Mutual Inductance of solenoid-coil system

$$M = \frac{\mu_0 N_1 N_2 A}{l}$$

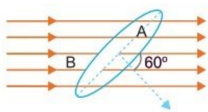
where A is area of coil, l is length of solenoid, N_1 is number of turns in solenoid and N_2 is number of turns in coil.

Multiple Choice Questions

Choose and write the correct option(s) in the following questions.

1. **Whenever the flux linked with a circuit changes, there is an induced emf in the circuit. This emf in the circuit lasts**
   (*a*) for a very short duration
   (*b*) for a long duration
   (*c*) forever
   (*d*) as long as the magnetic flux in the circuit changes.

2. **An area $A = 0.5\ m^2$ shown in the figure is situated in a uniform magnetic field $B = 4.0\ Wb/m^2$ and its normal makes an angle of 60° with the field. The magnetic flux passing through the area A would be equal to**

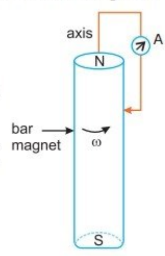


   (*a*) 2.0 weber (*b*) 1.0 weber (*c*) $\sqrt{3}$ weber (*d*) 0.5 weber

3. **A square of side L meters lies in the X-Y plane in a region, where the magnetic field is given by $B = B_o(2\hat{i} + 3\hat{j} + 4\hat{k})\ T$, where B_o is constant. The magnitude of flux passing through the square is** *[NCERT Exemplar]*
   (*a*) $2\ B_o\ L^2$ Wb (*b*) $3\ B_o\ L^2$ Wb (*c*) $4\ B_o\ L^2$ Wb (*d*) $\sqrt{29}\,B_o L^2$ Wb

4. **A loop, made of straight edges has six corners at $A(0, 0, 0)$, $B(L, 0, 0)$, $C(L, L, 0)$, $D(0, L, 0)$ $E(0, L, L)$ and $F(0, 0, L)$. A magnetic field $B = B_o(\hat{i} + \hat{k})\ T$ is present in the region. The flux passing through the loop $ABCDEFA$ (in that order) is** *[NCERT Exemplar]*
   (*a*) $B_o\ L^2$ Wb (*b*) $2\ B_o\ L^2$ Wb (*c*) $\sqrt{2}\,B_o L^2$ Wb (*d*) $4\ B_o\ L^2$ Wb

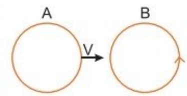
5. **An emf is produced in a coil, which is not connected to an external voltage source. This can be due to** *[NCERT Exemplar]*
   (*a*) the coil being in a time varying magnetic field.
   (*b*) the coil moving in a time varying magnetic field.
   (*c*) the coil moving in a constant magnetic field.
   (*d*) the coil is stationary in external spatially varying magnetic field, which does not change with time.



6. **A cylindrical bar magnet is rotated about its axis (Figure given alongside). A wire is connected from the axis and is made to touch the cylindrical surface through a contact. Then** *[NCERT Exemplar]*
   (*a*) a direct current flows in the ammeter A.
   (*b*) no current flows through the ammeter A.
   (*c*) an alternating sinusoidal current flows through the ammeter A with a time period $T = 2\pi/\omega$.
   (*d*) a time varying non-sinusoidal current flows through the ammeter A.

7. **A copper ring is held horizontally and a magnet is dropped through the ring with its length along the axis of the ring. The acceleration of the falling magnet is**
   (*a*) equal to that due to gravity
   (*b*) less than that due to gravity
   (*c*) more than that due to gravity
   (*d*) depends on the diameter of the ring and the length of the magnet

8. **There are two coils A and B as shown in the figure. A current starts flowing in B as shown, when A is moved towards B and stops when A stops moving. The current in A is counter clockwise. B is kept stationary when A moves. We can infer that** **[*NCERT Exemplar*]**



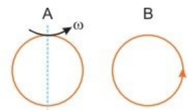
(*a*) there is a constant current in the clockwise direction in A.

(*b*) there is a varying current in A.

(*c*) there is no current in A.

(*d*) there is a constant current in the counterclockwise direction in A.

9. **Same as the above problem except the coil *A* is made to rotate about a vertical axis refer to the figure. No current flows in *B* if *A* is at rest. The current in coil *A*, when the current in *B* (at $t = 0$) is counterclockwise and the coil *A* is as shown at this instant, $t = 0$, is** **[*NCERT Exemplar*]**



(*a*) constant current clockwise.
(*b*) varying current clockwise.
(*c*) varying current counterclockwise.
(*d*) constant current counterclockwise.

10. **Lenz's law is essential for**

(*a*) conservation of energy
(*b*) conservation of mass
(*c*) conservation of momentum
(*d*) conservation of charge

11. **The self inductance *L* of a solenoid of length *l* and area of crosssection *A*, with a fixed number of turns *N* increases as** **[*NCERT Exemplar*]**

(*a*) *l* and *A* increase.
(*b*) *l* decreases and *A* increases.
(*c*) *l* increases and *A* decreases.
(*d*) both *l* and *A* decrease.

12. **A thin circular ring of area *A* is held perpendicular to a uniform magnetic field of induction *B*. A small cut is made in the ring and a galvanometer is connected across its ends in such a way that the total resistance of the circuit is *R*. When the ring is suddenly squeezed to zero area, the charge flowing through the galvanometer is**

(*a*) $\frac{BR}{A}$
(*b*) $\frac{AB}{R}$
(*c*) ABR
(*d*) $\frac{B^2A}{R^2}$

13. **A circular coil expands radially in a region of magnetic field and no electromotive force is produced in the coil. This can be because** **[*NCERT Exemplar*]**

(*a*) the magnetic field is constant.

(*b*) the magnetic field is in the same plane as the circular coil and it may or may not vary.

(*c*) the magnetic field has a perpendicular (to the plane of the coil) component whose magnitude is decreasing suitably.

(*d*) there is a constant magnetic field in the perpendicular (to the plane of the coil) direction.

14. **A thin diamagnetic rod is placed vertically between the poles of an electromagnet. When the current in the electromagnet is switched on, then the diamagnetic rod is pushed up, out of the horizontal magnetic field. Hence the rod gains gravitational potential energy. The work required to do this comes from**

(*a*) the current source

(*b*) the magnetic field

(*c*) the lattice structure of the material of the rod

(*d*) the induced electric field due to the changing magnetic field

15. **A circular loop of radius *r*, carrying a current *I* lies in *y-z* plane with its centre at the origin. The net magnetic flux through the loop is** **[*CBSE 2020 (55/4/1)*]**

(*a*) directly proportional to *r*

(*b*) zero

(*c*) inversely proportional to *r*

(*d*) directly proportional to *I*

16. The self-inductance of a solenoid of 600 turns is 108 mH. The self-inductance of a coil having 500 turns with the same length, the same radius and the same medium will be

[CBSE 2022 (55/2/4), Term-1]

(*a*) 95 mH (*b*) 90 mH (*c*) 85 mH (*d*) 75 mH

17. The current in the primary coil of a pair of coils changes from 7A to 3A in 0.04 s. The mutual inductance between the two coils is 0.5 H. The induced emf in the secondary coil is

[CBSE 2022 (55/2/4), Term-1]

(*a*) 50 V (*b*) 75 V (*c*) 100 V (*d*) 220 V

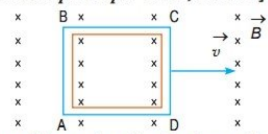
18. A conducting square loop of side 'L' and resistance 'R' moves in its plane with the uniform velocity 'v' perpendicular to one of its sides. A magnetic induction 'B' constant in time and space pointing perpendicular and into the plane of the loop exists everywhere as shown in the figure. The current induced in the loop is *[CBSE Sample Paper-2022, Term-1]*

(*a*) BLv/R clockwise

(*b*) BLv/R anticlockwise

(*c*) $2BLv/R$ anticlockwise

(*d*) zero



19. Two coils are placed close to each other. The mutual inductance of the pair of coils depends upon the *[CBSE Sample Paper-2022, Term-1]*

(*a*) rate at which current change in the two coils

(*b*) relative position and orientation of the coils

(*c*) rate at which voltage induced across two coils

(*d*) currents in the two coils

20. The magnetic flux linked with the coil (in weber) is given by the equation,

$$\phi = 5t^2 + 3t + 16$$

The induced EMF in the coil at time, $t = 4$ will be *[CBSE Sample Paper-2022, Term-1]*

(*a*) – 27 V (*b*) – 43 V (*c*) – 108 V (*d*) 210 V

21. A circular loop of radius 0.3 cm lies parallel to much bigger circular loop of radius 20 cm. The centre of the small loop is on the axis of the bigger loop. The distance between their centres is 15 cm. If a current of 2.0 A flows through the smaller loop, then the flux linked with the bigger loop is *[CBSE Sample Paper-2022, Term-1]*

(*a*) 3.3×10^{-11} weber (*b*) 6×10^{-11} weber (*c*) 6.6×10^{-9} weber (*d*) 9.1×10^{-11} weber

22. If both the number of turns and core length of an inductor is doubled keeping other factors constant, then its self-inductance will be *[CBSE Sample Paper-2022, Term-1)]*

(*a*) unaffected (*b*) doubled (*c*) halved (*d*) quadrupled

23. A circular coil of radius 8.0 cm and 40 turns is rotated about its vertical diameter with an angular speed off $\frac{25}{\pi}$ rad s^{-1} in a uniform horizontal magnetic field of magnitude 3.0×10^{-2} T. The maximum emf induced in the coil is *[CBSE 2023 (55/1/1)]*

(*a*) 0.12 V (*b*) 0.15 V (*c*) 0.19 V (*d*) 0.22 V

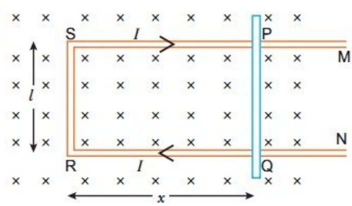
24. Figure shows a rectangular conductor *PSRQ* in which movable arm *PQ* has a resistance '*r* and resistance of *PSRQ* is negligible. The magnitude of emf induced when *PQ* is moved with a velocity $\vec{v}$ does not depend on *[CBSE 2020 (55/4/1)]*

(*a*) magnetic field $\vec{B}$

(*b*) velocity field $\vec{v}$

(*c*) resistance (r)

(*d*) length of *PQ*



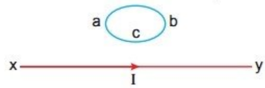
25. **The direction of induced current in the loop *abc* is** [*CBSE 2023 (55/4/1)*]

(*a*) along *abc* if *I* decreases

(*b*) along *acb* if *I* increases

(*c*) along *abc* if *I* constant

(*d*) along *abc* if *I* increases



Answers

1. (*d*)	**2.** (*b*)	**3.** (*c*)	**4.** (*b*)	**5.** (*a*), (*b*), (*c*)	**6.** (*b*)	**7.** (*b*)
8. (*d*)	**9.** (*a*)	**10.** (*a*)	**11.** (*b*)	**12.** (*b*)	**13.** (*b*), (*c*)	**14.** (*a*)
15. (*b*)	**16.** (*d*)	**17.** (*a*)	**18.** (*d*)	**19.** (*b*)	**20.** (*b*)	**21.** (*d*)
22. (*b*)	**23.** (*c*)	**24.** (*c*)	**25.** (*d*)			

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(a) Both A and R are true and R is the correct explanation of A.

(b) Both A and R are true but R is not the correct explanation of A.

(c) A is true but R is false.

(d) A is false and R is also false.

1. **Assertion(*A*)** : An emf is induced in a closed loop where magnetic flux is varied. The induced field $\vec{E}$ is not a conservative field.

   Reason (*R*) : The line integral $\oint \vec{E}.\vec{dl}$ around a closed path is non-zero. [*AIIMS 2006*]

2. **Assertion(*A*)** : Faraday established induced emf experimentally.

   Reason (*R*) : Magnetic flux can produce an induced emf.

3. **Assertion(*A*)** : The direction of induced emf is always such as to oppose the changes that causes it.

   Reason (*R*) : The direction of induced emf is given by Lenz's law .

4. **Assertion(*A*)** : Acceleration of a vertically falling magnet through a horizontal metallic ring is less than *g*.

   Reason (*R*) : Current induced in the ring opposes the fall of magnet.

5. **Assertion(*A*)** : Only a change of magnetic flux will maintain an induced current in the coil.

   Reason (*R*) : The presence of a large magnetic flux will maintain an induced current in the coil.

6. **Assertion(*A*)** : The presence of large magnetic flux through a coil maintains a current in the coil, if the circuit is continuous.

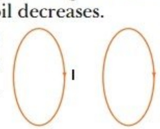
   Reason (*R*) : Only a change in magnetic flux will maintain an induced current in the coil. [*AIIMS 2018*]

7. **Assertion(*A*)** : If we use a battery across the primary of a step up transformer, then voltage is also obtained across secondary.

   Reason (*R*) : Battery gives a time varying current, so there is a change in magnetic flux through the secondary of transformer and hence, emf is induced across secondary.

8. **Assertion(*A*)** : Two identical co-axial circular coils carry equal currents circulating in same direction. If coils approach each other, the current in each coil decreases.

   Reason (*R*) : When coils approach each other, the magnetic flux linked with each coil increases. According to Lenz's law, the induced current in each coil will oppose the increase in magnetic flux, hence, the current in each coil will decrease.



9. **Assertion** (*A*) : When a rod moves in a transverse magnetic field, an emf is induced in the rod; the end becomes magnetic with end *A* positive.

Reason (*R*) : A Lorentz force evB acts on free electrons, so electrons move from *B* to *A*, thus by making end *A* positive and end *B* negative.

10. **Assertion** (*A*) : In the phenomenon of mutual induction, self-induction of each of the coils persists

Reason (*R*) : Self-induction arises when strength of current in same coil changes. In mutual induction, current is changed in both individual coils.

Answers

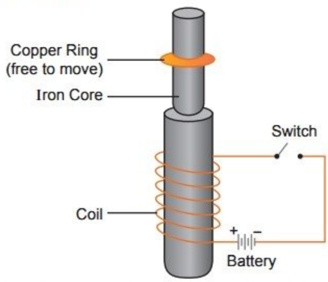
1. (*a*) **2.** (*c*) **3.** (*b*) **4.** (*a*) **5.** (*c*) **6.** (*d*) **7.** (*a*)
8. (*a*) **9.** (*b*) **10.** (*b*)

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Case-based/Passage-based Questions

Read the paragraph given below and answer the questions that follow:

Electromagnetic Induction: Consider the experimental set up shown in the figure. This jumping ring experiment is an outstanding demonstration of some simple laws of Physics. A conducting non-magnetic ring is placed over the vertical core of a solenoid. When current is passed through the solenoid, the ring is thrown off. **[*CBSE 2023 (55/2/1), Modified*]**



(*i*) The direction of induced current in the ring in jumping ring experiment is such that the polarity developed in the ring is same as that of the polarity on the face of the coil, then ring will jump up due to

(*a*) attractive force when the switch is closed in the circuit.
(*b*) repulsive force when the switch is closed in the circuit.
(*c*) attractive force when the switch is closed in the circuit.
(*d*) repulsive force when the switch is closed in the circuit.

(*ii*) What will happen if the terminals of the battery are reversed and the switch is closed?

(*a*) Ring will not be jump.
(*b*) Ring will jump again.
(*c*) Current will not induced in the ring.
(*d*) none of these

(*iii*) The jumping ring experiment based on which of the following law?

(*a*) Lenz's Law (*b*) Faraday's law
(*c*) Snell's Law (*d*) both (*a*) and (*b*)

(*iv*) **Two identical circular loops *A* and *B* of metal wire are lying on a table without touching each other. Loop *A* carries a current which increases with time. In response the loop *B***

(*a*) remains stationary.

(*b*) is attracted by loop *A*.

(*c*) is repelled by loop *A*.

(*d*) rotates about its centre of mass with centre of mass fixed.

OR

An emf of 200 V is induced in a circuit when current in the circuit falls from 5 A to 0 A in 0.1 second. The self-inductance of the circuit is

(*a*) 3.5 H (*b*) 3.9 H

(*c*) 4 H (*d*) 4.2 H

Explanations

(*i*) (*b*) The direction of induced current in the ring is such that the polarity developed in the ring is same as that of the polarity on the face of the coil, hence it will jump up due to repulsive force.

(*ii*) (*b*) The polarity of the induced current in the ring will get reversed on changing the terminals of the battery, so the ring will jump again.

(*iii*) (*d*) **Lenz's law:** It states that the polarity of induced emf is such that it tends to produce a current which opposes the change in magnetic flux that produces it.

Faraday's law of EMI:

Whenever there is change in magnetic flux through a coil, an emf is induced.

The magnitude of the induced emf in a coil is equal to the time rate of change of change of magnetic flux through the coil.

(*iv*) (*c*) Opposite currents are induced in loops, so loops repel each other.

OR

(*c*) Self inductance, $L = \dfrac{e}{\left(\dfrac{\Delta I}{\Delta t}\right)} = \dfrac{200}{\left(\dfrac{5}{0.1}\right)} = 4\text{ H}$

CONCEPTUAL QUESTIONS

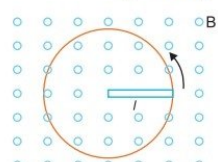
Q. 1. Two spherical bobs, one metallic and the other of glass, of the same size are allowed to fall freely from the same height above the ground. Which of the two would reach earlier and why?

[*CBSE Delhi 2014*]

Ans. Glass would reach earlier. This is because there is no effect of electromagnetic induction in glass, due to presence of earth's magnetic field, unlike in the case of metallic ball.

Q. 2. A 1.0 m metallic rod is rotated with an angular velocity of 400 rad/s about an axis normal to the rod passing through its one end. The other end of the rod is in contact with a circular metallic ring. A constant and uniform magnetic field of 0.5 T parallel to the axis exists everywhere. Calculate the emf developed between the centre and the ring. **[*NCERT*]**

Ans. EMF developed between the centre of ring and the point on the ring.



$$\varepsilon = \frac{1}{2} B\omega l^2$$

Given $B = 0.5$ T, $\omega = 400$ rad/s, $l = 1.0$ m.

$\therefore \quad \varepsilon = \frac{1}{2} \times 0.5 \times 400 \times (1.0)^2 = \mathbf{100\ volt}$

Q. 3. A long straight current carrying wire passes normally through the centre of circular loop. If the current through the wire increases, will there be an induced emf in the loop? Justify. **[*CBSE Delhi 2017*]**

Ans. No.

Justification: As the magnetic field due to current carrying wire will be in the plane of the circular loop, so magnetic flux will remain zero. Also, magnetic flux does not change with the change in current.

Q. 4. A solenoid with N loops of wire tightly wrapped around an iron-core is carrying an electric current I. If the current through this solenoid is reduced to half, then what change would you expect in inductance L of the solenoid? **[*CBSE Sample Paper 2021*]**

Ans. The inductance is given as,

$$L = \mu_0 \frac{N^2 A}{l}$$

Since the inductance does not depend upon the amount of current, the inductance of solenoid remains same.

Q. 5. On what factors does the magnitude of the emf induced in the circuit due to magnetic flux depend? **[*CBSE (F) 2013*]**

Ans. It depends on the rate of change in magnetic flux (or simply change in magnetic flux).

$$|\varepsilon| = \frac{\Delta \phi}{\Delta t}$$

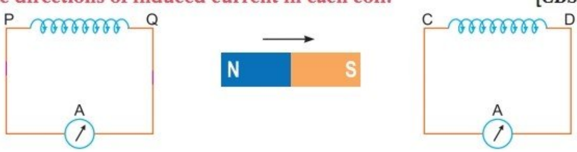
Q. 6. A conducting rod of length l is kept parallel to a uniform magnetic field $\vec{B}$. It is moved along the magnetic field with a velocity $\vec{v}$. What is the value of emf induced in the conductor. **[*CBSE 2020 (55/2/1)*]**

Ans.

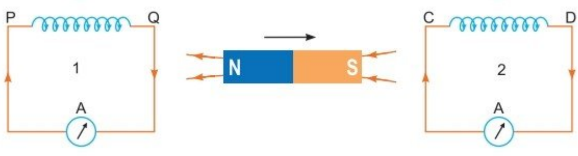
(17) A conducting rod of length l is kept parallel to a uniform magnetic field $\vec{B}$ and moved along it with velocity $\vec{v}$. The va of emf induced = 0.

[*Topper's Answer 2020*]

Q. 7. A bar magnet is moved in the direction indicated by the arrow between two coils PQ and CD. Predict the directions of induced current in each coil. **[*CBSE (AI) 2012, 2017*]**



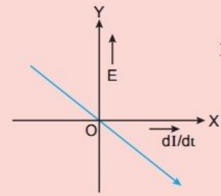
Ans.



In figure, N-pole is receding away coil (PQ), so in coil (PQ), the nearer faces will act as S-pole and in coil (CD) the nearer face will also act as S-pole to oppose the approach of magnet towards coil (CD), so currents in coils will flow clockwise as seen from the side of magnet. The direction of current will be from P to Q in coil (PQ) and from C to D in coil (CD).

Q. 8. Plot a graph showing variation of induced e.m.f. with the rate of change of current flowing through a coil. **[*CBSE 2020 (55/5/1)*]**

Ans. Induced e.m.f. in a coil, $\varepsilon = -L\dfrac{dI}{dt}$



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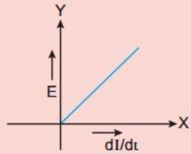
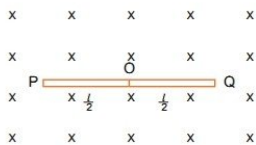
[Award one full mark even if the student just draws the graph without writing the expression of induced emf]

(**Note:** Award this one mark if a student draws the graph in first quadrant as shown below,)



[*CBSE Marking Scheme 2020 (55/5/1)*]

Q. 9. A metallic rod *PQ* of length *l* is rotated with an angular with an angular velocity ω in a magnetic field $\vec{B}$ about an axis passing through the mid-point *O* of the rod and perpendicular to the plane of paper as shown in the figure. What is the potential difference developed between the point *O* and *Q* of the rod? **[*CBSE 2020 (55/2/3)*]**



Ans. Emf induced in the rod, $\varepsilon = \dfrac{1}{2}B\omega l^2$

for Emf induced between O and Q, $\varepsilon = \dfrac{1}{2}B\omega\left(\dfrac{l}{2}\right)^2 = \dfrac{1}{8}B\omega l^2$

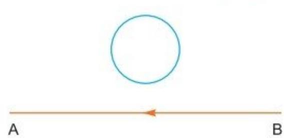
Q. 10. Predict the directions of induced currents in metal rings 1 and 2 lying in the same plane where current *I* in the wire is increasing steadily.

[*CBSE, (AI) 2017*]

Ans. 2. When current is increasing, magnetic flux linked with the two coils also increases. The $\vec{B}$ due to the current element in 2 is into the plane and 1 is out of the plane. Since flux increases direction of induced current is oppo such that the $\vec{B}$ due to it is opposite to the original flux. So the induced current in the loop 1 is in clockwise direction and 2 is in anticlockwise direction

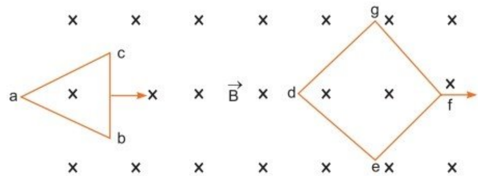
[*Topper's Answer 2017*]

Q. 11. The electric current flowing in a wire in the direction from *B* to *A* is decreasing. Find out the direction of the induced current in the metallic loop kept above the wire as shown. **[*CBSE (AI) 2014*]**



Ans. The current in the wire produces a magnetic field vertically downward in the vicinity of the coil. When the current in wire BA decreases, according to Lenz's law, the current induced in the coil opposes this decrease; so the current in the coil will be in clockwise direction.

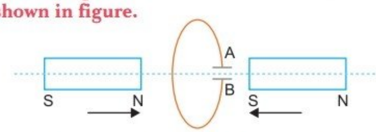
Q. 12. Two loops of different shapes are moved in the region of a uniform magnetic field pointing downward. The loops are moved in the directions shown by arrows. What is the direction of induced current in each loop? [*CBSE (F) 2010*] [*HOTS*]



Ans. Loop *abc* is entering the magnetic field, so magnetic flux linked with it begins to increase. According to Lenz's law, the current induced opposes the increases in magnetic flux, so current induced will be **anticlockwise** which tends to decrease the magnetic field.

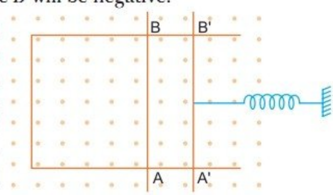
Loop *defg* is leaving the magnetic field; so flux linked with it tends to decrease, the induced current will be **clockwise** to produce magnetic field downward to oppose the decrease in magnetic flux.

Q. 13. Predict the polarity of the capacitor C connected to coil, which is situated between two bar magnets moving as shown in figure. [*CBSE Delhi 2011, (AI) 2017*]



Ans. Current induced in coil will oppose the approach of magnet; therefore, left face of coil will act as N-pole and right face as S-pole. For this the current in coil will be anticlockwise as seen from left, therefore, the plate A of capacitor will be positive and plate B will be negative.

Q. 14. A rectangular wire frame, shown below, is placed in a uniform magnetic field directed upward and normal to the plane of the paper. The part AB is connected to a spring. The spring is stretched and released when the wire AB has come to the position $A'\,B'$ ($t = 0$) How would the induced emf vary with time? Neglect damping. [*HOTS*]



Ans. When the spring is stretched and released, the wire AB will execute simple harmonic (sinusoidal) motion. So, the displacement of wire AB at any instant will be

$$x = -a\cos\omega t \qquad [\text{at } t = 0, x = -a]$$

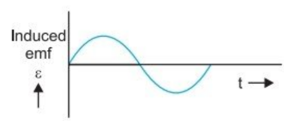
Magnetic flux linked with the loop at any instant,

$$\phi(t) = BA = Blx = -Bla\cos\omega t \qquad [\because A = lx]$$

By Faraday's law, emf induced across AB,

$$\varepsilon(t) = \frac{-d\phi}{dt} = \frac{-d}{dt}(-Bla\cos\omega t)$$

$$= Bla\omega\sin\omega t = \varepsilon_0\sin\omega t \qquad [\because \varepsilon_0 = Bla\omega]$$



Sinusoidal variation of induced emf

where $a = BB' = AA'$ is the amplitude of motion and ω is angular frequency.

Clearly induced emf $\varepsilon(t)$ Varies sinusoidally with time.

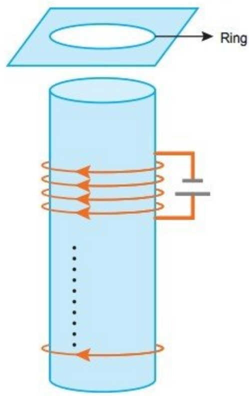
Q. 15. A wire in the form of a tightly wound solenoid is connected to a *DC* source, and carries a current. If the coil is stretched so that there are gaps between successive elements of the spiral coil, will the current increase or decrease? Explain. [*NCERT Exemplar*]

Ans. The current will increase. As the wires are pulled apart the flux will leak through the gaps. Lenz's law demands that induced emf resist this decrease, which can be done by an increase in current.

Q. 16. A solenoid is connected to a battery so that a steady current flows through it. If an iron core is inserted into the solenoid, will the current increase or decrease? Explain. [*NCERT Exemplar*]

Ans. The current will decrease. As the iron core is inserted in the solenoid, the magnetic field increases and the flux increases. Lenz's law implies that induced emf should resist this increase, which can be achieved by a decrease in current. However, this change will be momentarily.

Q. 17. Consider a metal ring kept (supported by a cardboard) on top of a fixed solenoid carrying a current *I* (in figure). The centre of the ring coincides with the axis of the solenoid. If the current in the solenoid is switched off, what will happen to the ring? [*NCERT Exemplar*]



Ans. When the current in the solenoid decreases a current flows in the same direction in the metal ring as in the solenoid. Thus there will be a downward force. This means the ring will remain on the cardboard. The upward reaction of the cardboard on the ring will increase.

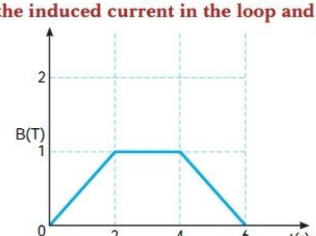
CONSTRUCTED RESPONSE QUESTIONS AS PER NEP

Very Short Answer Questions

Each of the following questions are of 2 marks.

Q. 1. The magnetic field through a circular loop of wire 12 cm in radius and 8.5 Ω resistance, changes with time as shown in the figure. The magnetic field is perpendicular to the plane of the loop. Calculate the induced current in the loop and plot it as a function of time.

[*CBSE (F) 2017*]



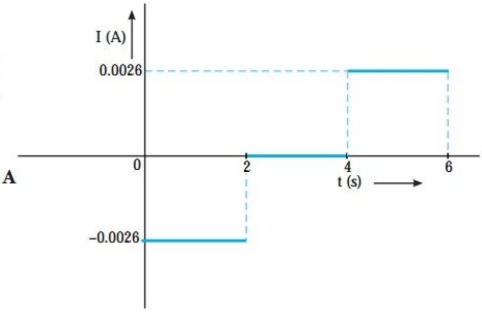
Ans. We know,

$$\varepsilon = \frac{-d\phi}{dt} = \frac{-d(BA)}{dt} = -A\frac{dB}{dt}$$

$$I = \frac{\varepsilon}{R} = \frac{-A\left(\frac{dB}{dt}\right)}{R} = \frac{-\pi r^2\left(\frac{dB}{dt}\right)}{R}$$

For $0 < t < 2$

$$I = \frac{-3.14(0.12)^2 \times 1}{2 \times 8.5} = \mathbf{-0.0026\ A}$$



For, $2 < t < 4$

$$\frac{dB}{dt} = 0 \quad \Rightarrow \quad I = \mathbf{0}$$

For, $4 < t < 6$

$$I = \mathbf{+\ 0.0026\ A}$$

Q. 2. A horizontal conducting rod 10 m long extending from east to west is falling with a speed 5 ms^{-1} at right angles to the horizontal component of the Earth's magnetic field 0.3×10^{-4} Wbm^{-2}. Find the instantaneous value of the emf induced in the rod. **[*CBSE (AI) 2017*]**

Ans.

(b) The rod is moving perpendicular to the magnetic field

so

$\varepsilon = Blv$

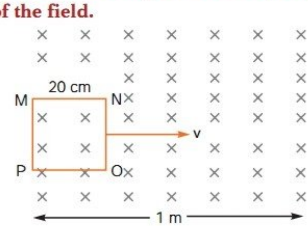
$= 0.3 \times 10^{-4}\ \text{Wbm}^{-2} \times 10\ \text{m} \times 5\ \text{ms}^{-1}$

$= 0.3 \times 10^{-4} \times 10 \times 5\ \text{V}$

$= 1.5 \times 10^{-3}\ \text{V}$

[*Topper's Answer 2017*]

Q. 3. A square loop *MNOP* of side 20 cm is placed horizontally in a uniform magnetic field acting vertically downwards as shown in the figure. The loop is pulled with a constant velocity of 20 cms^{-1} till it goes out of the field.



(*i*) Depict the direction of the induced current in the loop as it goes out of the field. For how long would the current in the loop persist?

(*ii*) Plot a graph showing the variation of magnetic flux and induced emf as a function of time.

[*CBSE Panchkula 2015*]

Ans. (*i*) Clockwise *MNOP*.

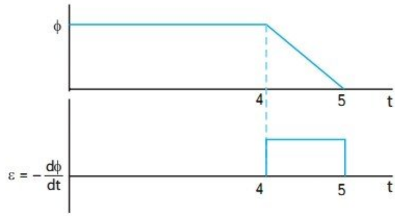
$$v = 20\ \text{cm/s};\ d = 20\ \text{cm}$$

Time taken by the loop to move out of magnetic field

$$t = \frac{d}{v} = \frac{20}{20} = \mathbf{1s}$$

Induced current will last for 1 second till the length 20 cm moves out of the field.

(*ii*)



Q. 4. A coil of wire enclosing an area 100 cm^2 is placed with its plane making an angle 60° with the magnetic field of strength 10^{-1}T. What is the flux through the coil? If magnetic field is reduced to zero in 10^{-3} s, then find the induced emf. [*CBSE Sample Paper 2021*]

Ans. Given, $A = 100\text{ cm}^2 = 100 \times 10^{-4}\text{ m}^2 = 10^{-2}\text{ m}^2,\ B = 10^{-1}\text{ T}$

Angle made by coil with magnetic field = 60°

Angle made by normal to plane of coil with magnetic field = 30°

Flux, $\phi = BA\cos\theta$

$$= 10^{-1} \times 10^{-2} \times \cos 30° = \frac{\sqrt{3}}{2} \times 10^{-3}\text{ Wb}$$

After $t = 10^{-3}$ s, $B = 0$

Induce emf, $E = -\dfrac{d\phi}{dt} = -\left(\dfrac{0 - \dfrac{\sqrt{3}}{2}\times 10^{-3}}{10^{-3}}\right) = \dfrac{\boldsymbol{\sqrt{3}}}{\mathbf{2}}\mathbf{V}$

Q. 5. The energy stored in a solenoid of inductance *L* is *U*. The number of turns per unit length of the solenoid is doubled. Keeping the current and all other factors same, find (*a*) change in inductance of the solenoid, and (*b*) the final energy stored in the inductor. [*CBSE 2020 (55/3/2)*]

Ans. (*a*) Self-inductance, $L = \mu_0 \mu_r n^2 A l$

or alternatively, $L \propto n^2$ ½

So, L becomes, 4 times ½

(*b*) Energy stored, $U = \frac{1}{2} LI^2$ ½

As L increases 4 times, energy also increases 4 times. ½

[*CBSE Marking Scheme 2020 (55/3/2)*]

Q. 6. (*i*) Define mutual inductance.

(*ii*) A pair of adjacent coils has a mutual inductance of 1.5 H. If the current in one coil changes from 0 to 20 A in 0.5 s, what is the change of flux linkage with the other coil? [*CBSE Delhi 2016*]

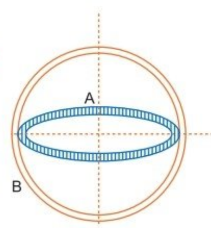
Ans. (*i*) Mutual inductance of two coils is the magnetic flux linked with the secondary coil when a unit current flows through the primary coil,

i.e., $\phi_2 = MI_1$ or $M = \dfrac{\phi_2}{I_1}$

(*ii*) Change of flux for small change in current

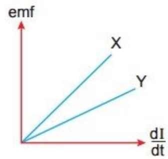
$$d\phi = MdI = 1.5\,(20 - 0)\text{ weber} = \mathbf{30\ weber}$$

Q. 7. Two coils of wire *A* and *B* are placed mutually perpendicular as shown in figure. When current is changed in any one coil, will the current induce in another coil?



Ans. No; this is because the magnetic field due to current in coil (*A* or *B*) will be parallel to the plane of the other coil (*A* or *B*) Hence, the magnetic flux linked with the other coil will be zero and so no current will be induced in it.

Q. 8. The figure shows the variation of induced emf as a function of rate of change of current for two identical solenoids *X* and *Y*. One is air cored and the other is iron cored. Which one of them is iron cored? why? **[*CBSE 2023 (55/4/1)*]**



Ans. From the graph, slope $= \dfrac{\varepsilon}{\dfrac{dI}{dt}} = L$

Slope of *X* is more than that of *Y*. Hence *X* is iron-cored because inductance of iron cored coil is more than that of air-cored coil.

Q. 9. A small flat search coil of area 5 cm^2 with 140 closely wound turns is placed between the poles of a powerful magnet producing magnetic field 0.09 T and then quickly removed out of the field region. Calculate **[*CBSE 2019 (55/3/1)*]**

(*a*) change of magnetic flux through the coil, and

(*b*) emf induced in the coil.

Ans. (*a*) M flux $\phi_1 = N\vec{B}.\vec{A} = NBA\cos\theta$

$= NBA\cos 0° = NBA$

$= 140\times 0.09\times 5\times 10^{-4} = 63\times 10^{-4}$ Wb

$\phi_2 = NBA \qquad [\because B = 0]$

$= 0$

Change in magnetic flux $= \phi_2 - \phi_1$

$= \mathbf{63 \times 10^{-2}}$ **Wb**

(*b*) εmf induced $= -\dfrac{d\phi}{dt} = \dfrac{-63\times 10^{-4}}{\Delta t}$.

[Here time is not given. Question is incomplete.]

Q. 10. A 0.5 m long solenoid of 10 turns/cm has area of cross-section 1 cm^2. Calculate the voltage induced across its ends if the current in the solenoid is changed from 1A to 2A in 0.1s. **[*CBSE 2019 (55/3/1)*]**

Ans. Induced voltage,

$|V| = L\dfrac{dI}{dt}$ ½

$\therefore \quad |V| = \mu_0 n^2 la\dfrac{dI}{dt}$ ½

$= 4\pi\times 10^{-7}\times(\dfrac{10}{10^{-2}})^2\times 0.5\times 110^{-4}\times\dfrac{(2-1)}{0.1}$ ½

$= 6.28\times 10^{-4}$ V or 0.628 mV ½

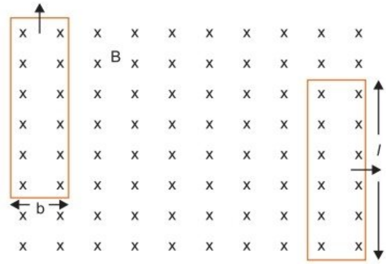
[*CBSE Marking Scheme 2019 (55/3/1)*]

Q. 11. A rectangular wire loop of sides 8 cm × 2 cm with a small cut is moving out of a region of uniform magnetic field of magnitude 0.3 T directed normal to the loop. What is the emf developed if the velocity of the loop is 1 cms^{-1} in a direction normal to the (*i*) longer side (*ii*) shorter side of the loop? For how long does the induced voltage last in each case? **[*NCERT*]**

Ans. Given $l = 8 \text{ cm} = 8 \times 10^{-2} \text{ m}$,

$b = 2 \text{ cm} = 2 \times 10^{-2} \text{ m}$

$v = 1 \text{ cm s}^{-1} = 1 \times 10^{-2} \text{ m/s}, B = 0.3 \text{ T}$



(*i*) When velocity is normal to the longer side

Induced emf, $\varepsilon = Bvl$

$= 0.3 \times 1 \times 10^{-2} \times 8 \times 10^{-2}$

$= \mathbf{24 \times 10^{-5} \text{ V}}$

emf will last only so long as the loop is in the magnetic field.

$$\text{Time taken} = \frac{\text{distance}}{\text{velocity}} = \frac{b}{v} = \frac{2 \times 10^{-2}}{1 \times 10^{-2}} = \mathbf{2 \text{ s}}$$

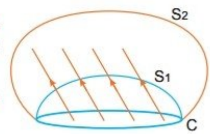
(*ii*) When velocity is normal to the shorter side

$\varepsilon_2 = Bvb$

$= 0.3 \times 1 \times 10^{-2} \times 2 \times 10^{-2} = \mathbf{6 \times 10^{-5} \text{ V}}$

$$\text{Time taken} = \frac{l}{v} = \frac{8 \times 10^{-2}}{1 \times 10^{-2}} = \mathbf{8 \text{ s}}$$

Q. 12. Consider a closed loop C in a magnetic field (see figure). The flux passing through the loop is defined by choosing a surface whose edge coincides with the loop and using the formula $\phi = \vec{B_1}.d\vec{A_1} + \vec{B_2}.d\vec{A_2}$ ... Now if we chose two different surfaces S_1 and S_2 having C as their edge, would we get the same answer for flux. Justify your answer. [*NCERT Exemplar*]



Ans. One gets the same answer for flux. Flux can be thought of as the number of magnetic field lines passing through the surface (we draw $dN = BA$ lines in a area ΔA perpendicular to B). As field lines of B cannot end or start in space (they form closed loops), number of lines passing through surface S_1 must be the same as the number of lines passing through the surface S_2.

Short Answer Questions

Each of the following questions are of 3 marks.

Q. 1. In an experimental arrangement of two coils C_1 and C_2 placed coaxially parallel to each other, find out the expression for the emf induced in the coil C_1 (of N_1 turns) corresponding to the change of current I_2 in the coil C_2 (of N_2 turns). [*CBSE Chennai 2015*]

Ans. Let ϕ_1 be the flux through coil C_1 (of N_1 turns) when current in coil C_2 is I_2. Then, we have

$$N_1\phi_1 = MI_2 \qquad ...(i)$$

For current varying with time,

$$\frac{d(N_1\phi_1)}{dt} = \frac{d(MI_2)}{dt} \qquad ...(ii)$$

Since induced *emf* in coil C_1 is given by

$$\varepsilon_1 = -\frac{d(N_1\phi_1)}{dt}$$

From (*ii*), $\quad -\varepsilon_1 = M\left(\dfrac{dI_2}{dt}\right)$

$$\varepsilon_1 = -M\frac{dI_2}{dt} \qquad \text{[from } (i)\text{]}$$

It shows that varying current in a coil induces emf in the neighbouring coil.

Q. 2. (*a*) How does the mutual inductance of a pair of coils change when

(*i*) distance between the coils is increased and

(*ii*) number of turns in the coils is increased? [*CBSE (AI) 2013*]

(*b*) A plot of magnetic flux (ϕ) versus current (*I*), is shown in the figure for two inductors *A* and *B*. Which of the two has large value of self-inductance? [*CBSE Delhi 2010*]

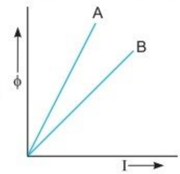
(*c*) How is the mutual inductance of a pair of coils affected when

(*i*) separation between the coils is increased?

(*ii*) the number of turns in each coil is increased?

(*iii*) a thin iron sheet is placed between the two coils, other factors remaining the same?

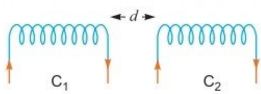
Justify your answer in each case. [*CBSE (AI) 2013*]



Ans. (*a*) (*i*) Mutual inductance decreases.

(*ii*) Mutual inductance increases.

Concept: (*i*) If distance between two coils is increased as shown in figure.



It causes decrease in magnetic flux linked with the coil C_2. Hence induced emf in coil C_2 decreases by relation $\varepsilon_2 = \dfrac{-d\varphi_2}{dt}$. Hence mutual inductance decreases.

(*ii*) From relation $M_{21} = \mu_0 n_1 n_2 Al$, if number of turns in one of the coils or both increases, means mutual inductance will increase.

(*b*) $\phi = LI \Rightarrow \dfrac{\phi}{I} = L$

The slope of $\dfrac{\phi}{I}$ of straight line is equal to self-inductance *L*. It is larger for inductor *A*; therefore inductor *A* has larger value of self inductance '*L*'.

(*c*) (*i*) When the relative distance between the coil is increased, the leakage of flux increases which reduces the magnetic coupling of the coils. So magnetic flux linked with all the turns decreases. Therefore, mutual inductance will be decreased.

(*ii*) Mutual inductance for a pair of coil is given by

$$M = K\sqrt{L_1 L_2}$$

where $L = \dfrac{\mu N^2 A}{l}$ and *L* is called self inductance. Therefore, when the number of turns in each coil increases, the mutual inductance also increases.

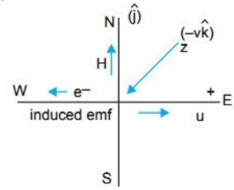
(*iii*) When a thin iron sheet is placed between the two coils, the mutual inductance increases because M$\propto$ permeability. The permeability of the medium between coils increases.

Q. 3. A horizontal straight wire 10 m long extending from east to west is falling with a speed of 5.0 ms^{-1} at right angles to the horizontal component of earth's magnetic field equal to 0.30 $\times 10^{-4}$ Wbm^{-2}. [*NCERT*]

(*a*) **What is the instantaneous value of the emf induced in the wire?**

(*b*) **What is the direction of emf?**

(*c*) **Which emf of the wire is at the higher electrical potential?**



Ans. (*a*) Instantaneous emf, $\varepsilon = B_n vl = Hvl$

Given, $H=0.30 \times 10^{-4}$ T, $v=5.0$ ms^{-1}, $l=10$ m

$\therefore \quad \varepsilon = 0.30 \times 10^{-4} \times 5.0 \times 10 = 1.5\times10^{-3}$ V$=$**1.5 mV**

(*b*) By Fleming's right hand rule, the direction of induced current in wire is from west to east, therefore, direction of emf is from west to east.

(*c*) The direction of electron flow according to relation $\vec{F}_m = q\vec{v}\times\vec{B} = -e(-v\hat{k})\times(B\hat{j}) = -evB\hat{i}$ *i.e.*, along negative *x*-axis, *i.e.*, from east to west.

The induced emf will oppose the flow of electrons from east to west, so eastern end will be at higher potential.

Q. 4. Define self-inductance of a coil. Show that magnetic energy required to build up the current *I* in a coil of self inductance *L* is given by $\frac{1}{2}LI^2$. **[*CBSE Delhi 2012*]**

OR

Define the term self-inductance of a solenoid. Obtain the expression for the magnetic energy stored in an inductor of self-inductance *L* to build up a current *I* through it. **[*CBSE (AI) 2014*]**

Ans. Self inductance – Using formula $\phi = LI$, if $I = 1$ Ampere then $L = \phi$

Self inductance of the coil is equal to the magnitude of the magnetic flux linked with the coil, when a unit current flows through it.

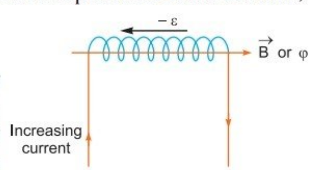
Alternatively

Using formula $|-\varepsilon| = L\dfrac{dI}{dt}$

If $\dfrac{dI}{dt} = 1$ A/s then $L = |-\varepsilon|$

Self inductance of the coil is equal to the magnitude of induced emf produced in the coil itself, when the current varies at rate 1 A/s.

Expression for magnetic energy



When a time varying current flows through the coil, back *emf* $(-\varepsilon)$ produces, which opposes the growth of the current flow. It means some work needs to be done against induced emf in establishing a current *I*. This work done will be stored as magnetic potential energy.

For the current *I* at any instant, the rate of work done is

$$\frac{dW}{dt} = (-\varepsilon)I$$

Only for inductive effect of the coil $|-\varepsilon| = L\dfrac{dI}{dt}$

$$\therefore \quad \frac{dW}{dt} = L\left(\frac{dI}{dt}\right)I \quad \Rightarrow \quad dW = LI\,dI$$

From work-energy theorem,

$$dU = LI\,dI$$

$$\therefore \quad U = \int_0^I LIdI = \frac{1}{2}LI^2$$

Q. 5. A long solenoid of radius r consists of n turns per unit length. A current $I = I_0 \sin \omega t$ flows in the solenoid. A coil of N turns is wound tightly around it near its centre. What is:

(*a*) the induced emf in the coil?

(*b*) the mutual inductance between the solenoid and the coil? [*CBSE 2023 (55/1/1)*]

Ans. Here, $I = I_0 \sin \omega t.$

For solenoid, $B = \mu_0 nI$

Magnetic flux, $\phi = BA = \mu_0 nI \times \pi r^2 = \mu_0 n\pi r^2 I_0 \sin \omega t.$

(*a*) *Emf* induced, $e = -\dfrac{Nd\phi}{dt} = -\dfrac{Nd}{dt}(BA) = -N\mu_0 n\pi r^2 \omega I_0 \cos \omega t$

$$= -(\mu_0 I_0 \omega N n\pi r^2) \cos \omega t = -e_0 \cos \omega t$$

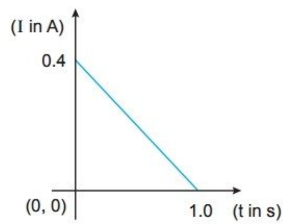
where, peak *emf*, $e_0 = \mu_0 I_0 \omega N n\pi r^2$

(*b*) Mutual inductance between the coil and solenoid,

$$\phi = MI$$

$$\therefore \quad M = \frac{N\phi}{I} = \frac{\mu_0 N n\pi r^2 I_0 \sin \omega t}{I_0 \sin \omega t} = \mu_0 N n\pi r^2$$

Q. 6. When a conducting loop of resistance 10 Ω and area 10 cm² is removed from an external magnetic field acting normally, the variation of induced current-I in the loop with time t is as shown in the figure. [*CBSE 2020 (55/5/1)*]



Find the

(*a*) total charge passed through the loop.

(*b*) change in magnetic flux through the loop.

(*c*) magnitude of the magnetic field applied.

Ans. (*a*) total charge passed through the loop (Q)

Q = area under the I-t graph ½

$= \dfrac{1}{2} \times 0.4 \times 1$ coulomb $= 0.2$ C ½

(*b*) Change in magnetic flux,

Total charge passing $= \left(\dfrac{\text{Change in magnetic flux}}{\text{R}}\right)$ ½

Change in magnetic flux = [$R \times 0.2$ C]

= [10×0.2] Wb = 2 Wb ½

(*c*) Magnitude of magnetic field applied,

Let B be the magnitude of the magnetic field applied.

Initial magnetic flux = $B \times (10 \times 10^{-4})$ Wb

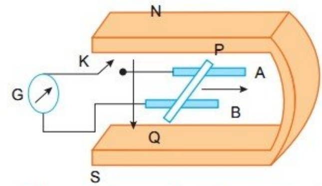
Final magnetic flux = zero

Change in magnetic flux = $(B \times 10^{-3} - 0) = 2$ ½

$\therefore \quad B = 2 \times 10^3$ Wb/m² ½

[*CBSE Marking Scheme 2020 (55/5/1)*]

Q. 7. Figure shows a metal rod PQ of length l, resting on the smooth horizontal rails AB positioned between the poles of a permanent magnet. The rails, rod and the magnetic field B are in three mutually perpendicular directions. A galvanometer G connects the rails through a key 'K'. Assume the magnetic field to be uniform. Given the resistance of the closed loop containing the rod is R.



(i) Suppose K is open and the rod is moved with a speed v in the direction shown. Find the polarity and the magnitude of induced emf.

(ii) With K open and the rod moving uniformly, there is no net force on the electrons in the rod PQ even though they do experience magnetic force due to the motion of the rod. Explain.

(iii) What is the induced emf in the moving rod if the magnetic field is parallel to the rails instead of being perpendicular? **[*CBSE Sample Paper 2018*]**

Ans. (i) The magnitude of the induced emf is given by

$$|\varepsilon| = Blv\sin\theta$$

As the conductor PQ moves in the direction shown, the free electrons in it experience magnetic Lorentz force. By Fleming's left hand rule, the electrons move from the end P towards the end Q. Deficiency of electrons makes the end P positive while the excess of electrons makes the end Q negative.

(ii) The magnetic Lorentz force $[\vec{F}_m = -e(\vec{v} \times \vec{B})]$ is cancelled by the electric force $[\vec{F}_m = e\vec{E}]$ exerted by the electric field set up by the opposite charges at its ends.

(iii) In this case, the angle θ made by the rod with the field $\vec{B}$ is zero.

$$\therefore \qquad \varepsilon = Blv\sin 0° = 0$$

This is because the motion of the loop does not cut across the field lines. There is no change in magnetic flux. So the induced emf is zero.

Q. 8. Two concentric circular loops of radius 1 cm and 20 cm are placed coaxially.

(i) Find mutual inductance of the arrangement.

(ii) If the current passed through the outer loop is changed at a rate of 5 A/ms, find the emf induced in the inner-loop. Assume the magnetic field on the inner loop to be uniform.

[*CBSE 2020 (55/5/1)*]

Ans. (i) Imagine a current I to flow through the largest coil.

Magnetic flux linked with the smaller coil,

$$\phi = B_{\text{centre}} \times \pi \times 10^{-4}\ \text{Wb} \qquad \tfrac{1}{2}$$

$$= \frac{\mu_0 I}{2 \times 20 \times 10^{-2}} \times \pi \times 10^{-4}\ \text{Wb}$$

Also, we know,

$$\phi = MI$$

$$\therefore \qquad M = \frac{\mu_0 \pi}{4} \times 10^{-3}\ \text{H} \qquad \tfrac{1}{2}$$

$$= \frac{4\pi \times 10^{-7} \pi \times 10^{-3}}{4}\ \text{H}$$

$$= 9.9 \times 10^{-10}\ \text{H}$$

$$= 10^{-9}\ \text{H} \qquad \tfrac{1}{2}$$

(ii) e.m.f. induced $= -M\dfrac{dI}{dt}$ ½

$= -10^{-9} \times \dfrac{5}{10^{-3}}$ V ½

$= -5 \times 10^{-6}$ V ½

Alternatively,

e.m.f. induced $= -\dfrac{d\phi}{dt}$

$= -\dfrac{d}{dt}(B_c A_i) = -A_i \dfrac{dB_c}{\text{dt}}$ ½

$= -A_i \dfrac{d}{dt}\left(\dfrac{\mu_0 I}{2R}\right)$

$= -\dfrac{A_i \mu_0}{2R}\dfrac{dI}{dt}$

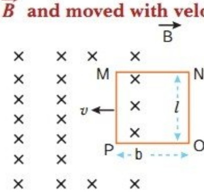
$= -\dfrac{\pi \times 10^{-4} \times 4\pi \times 10^{-7} \times 5}{2 \times (20 \times 10^{-2}) \times 10^{-3}}$ V ½

$= -\dfrac{20\pi^2 \times 10^{-6}}{2 \times 20}$ V

$= -5 \times 10^{-6}$ V ½

[*CBSE Marking Scheme 2020 (55/5/1)*]

Q. 9. The figure shows a rectangular conducting frame *MNOP* of resistance *R* placed partly in a perpendicular magnetic field $\vec{B}$ and moved with velocity $\vec{v}$ as shown in the figure.



Obtain the expressions for the

(a) force acting on the arm '*ON*' and its direction, and

(b) Power required to move the frame to get a steady emf induced between the arms *MN* and *PO*. [*CBSE 2019 (55/4/1)*]

Ans. (a) The induced emf in the moving conductor *MNOP*

$e = Blv$ ½

The induced correct, $i = \dfrac{e}{R} = \dfrac{Blv}{R}$

Force on the arm 'ON' $F = Bil$ ½

$= \dfrac{B^2 l^2 v}{R}$ ½

The force is directed in the direction opposite to velocity of rod (v). ½

Note: Award the last half mark if the student write $F = 0$ as $B = 0$ is the position shown

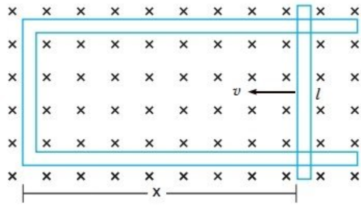
(b) Power $P = F \times v$ ½

$= \dfrac{B^2 l^2 v^2}{R}$ ½

Note: Award the last half mark if the student write $P = 0$ as $B = 0$ is the position shown.

[*CBSE Marking Scheme 2019 (55/4/1)*]

Q. 10. **(a) A rod of length l is moved horizontally with a uniform velocity 'v' in a direction perpendicular to its length through a region in which a uniform magnetic field is acting vertically downward. Derive the expression for the emf induced across the ends of the rod.**



(b) How does one understand this motional emf by invoking the Lorentz force acting on the free charge carriers of the conductor? Explain. **[*CBSE (AI) 2014*]**

Ans. (a) Suppose a rod of length 'l' moves with velocity v inward in the region having uniform magnetic field B.

Initial magnetic flux enclosed in the rectangular space is $\phi = |B|lx$

As the rod moves with velocity $-v = \dfrac{dx}{dt}$

Using Lenz's law

$$\varepsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}(Blx) = Bl\left(-\frac{dx}{dt}\right)$$

$$\therefore \qquad \varepsilon = Blv$$

(b) Suppose any arbitrary charge 'q' in the conductor of length 'l' moving inward in the field as shown in figure, the charge q also moves with velocity v in the magnetic field B.

The Lorentz force on the charge 'q' is $F = qvB$ and its direction is downwards.

So, work done in moving the charge 'q' along the conductor of length l

$$W = F.l$$

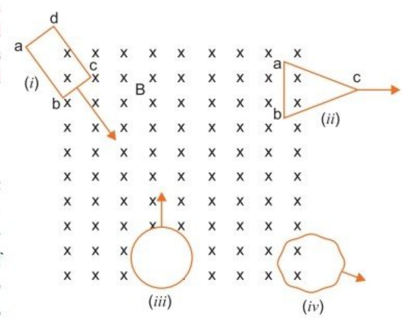
$$W = qvBl$$

Since emf is the work done per unit charge

$$\therefore \qquad \varepsilon = \frac{W}{q} = Blv$$

This equation gives emf induced across the rod.

Q. 11. **Figure shows planar loops of different shapes moving out of or into a region of magnetic field which is directed normal to the plane of loops downwards. Determine the direction of induced current in each loop using Lenz's law.** **[*CBSE (AI) 2010, (F) 2014*]**



Ans. (a) In Fig. (*i*) the rectangular loop *abcd* and in Fig. (*iii*) circular loop are entering the magnetic field, so the flux linked with them increases; The direction of induced currents in these coils, will be such as to oppose the increase of magnetic flux; hence the magnetic field due to current induced will be upward, *i.e.*, currents induced will flow *anticlockwise*.

(*b*) In Fig. (*ii*), the triangular loop *abc* and in fig. (*iv*) the zig-zag shaped loop are emerging from the magnetic field, therefore magnetic flux linked with these loops decreases. The currents induced in them will tend to increase the magnetic field in downward direction, so the currents will flow *clockwise*.

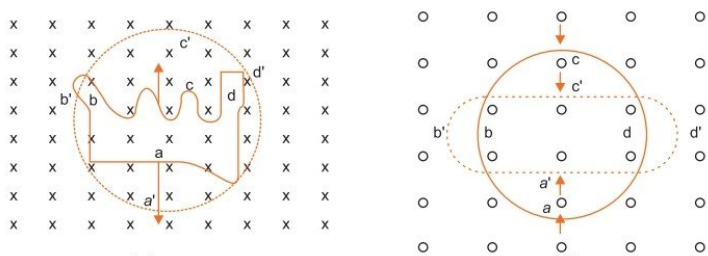
Thus in fig. (*i*) current flows anticlockwise,

in fig. (*ii*) current flows clockwise,

in fig. (*iii*) current flows anticlockwise,

in fig. (*iv*) current flows clockwise.

Q. 12. Use Lenz's law to determine the direction of induced current in the situation described by following figs.



(a) (b)

(*a*) A wire of irregular shape turning into a circular shape.

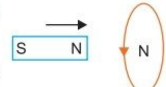
(*b*) A circular loop being deformed into a narrow straight wire. **[*CBSE (F) 2014*]**

Ans. (*a*) For the given periphery the area of a circle is maximum. When a coil takes a circular shape, the magnetic flux linked with coil increases, so current induced in the coil will tend to decrease the flux and so will produce a magnetic field upward. As a result the current induced in the coil will flow anticlockwise *i.e.,* along *a'd'c'b'*.

(*b*) For given periphery the area of circle is maximum. When circular coil takes the shape of narrow straight wire, the magnetic flux linked with the coil decreases, so current induced in the coil will tend to oppose the decrease in magnetic flux; hence it will produce upward magnetic field, so current induced in the coil will flow anticlockwise *i.e.*, along *a' d' c' b'*.

Q. 13. Show that Lenz's law is in accordance with the law of conservation of energy. [*CBSE (F) 2017*]

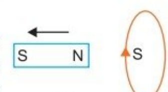
Ans. **Lenz's law:** According to this law "*the direction of induced current in a closed circuit is always such as to oppose the cause that produces it*."



(*a*)

Example: When the north pole of a coil is brought near a closed coil, the direction of current induced in the coil is such as to oppose the approach of north pole. For this the nearer face of coil behaves as north pole. This necessitates an anticlockwise current in the coil, when seen from the magnet side [fig. (*a*)]

Similarly when north pole of the magnet is moved away from the coil, the direction of current in the coil will be such as to attract the magnet. For this the nearer face of coil behaves as south pole. This necessitates a clockwise current in the coil, when seen from the magnet side [fig. (*b*)].



(*b*)

Conservation of Energy in Lenz's Law: In each case whenever there is a relative motion between a coil and the magnet, a force begins to act which opposes the relative motion. Therefore to maintain the relative motion, a mechanical work must be done. This work appears in the form of electric energy of coil. Thus, *Lenz's law is based on principle of conservation of energy*.

Long Answer Questions

Each of the following questions are of 5 marks.

Q. 1. (*a*) What is induced emf? Write Faraday's law of electromagnetic induction. Express it mathematically.

(*b*) A conducting rod of length '*l*', with one end pivoted, is rotated with a uniform angular speed 'ω' in a vertical plane, normal to a uniform magnetic field '*B*'. Deduce an expression for the emf induced in this rod. [*CBSE Delhi 2013, 2012*]

If resistance of rod is *R*, what is the current induced in it?

Ans. (*a*) **Induced emf:** The emf developed in a coil due to change in magnetic flux linked with the coil is called the induced emf.

Faraday's Law of Electromagnetic Induction: On the basis of experiments, Faraday gave two laws of electromagnetic induction:

1. *When the magnetic flux linked with a coil or circuit changes, an emf is induced in the coil.*

If coil is closed, the current is also induced. The emf and current last so long as the change in magnetic flux lasts. *The magnitude of induced emf is proportional to the rate of change of magnetic flux linked with the circuit*. Thus if $\Delta\phi$ is the change in magnetic flux linked in time Δt then rate of change of flux is $\frac{\Delta\phi}{\Delta t}$,

So emf induced $\qquad \varepsilon \propto \frac{\Delta\phi}{\Delta t}$

2. *The emf induced in the coil (or circuit) opposes the cause producing it.*

$$\varepsilon \propto -\frac{\Delta\phi}{\Delta t}$$

Here the negative sign shows that the induced emf 'ε' opposes the change in magnetic flux.

$$\varepsilon = -K\frac{\Delta\phi}{\Delta t}$$

where K is a constant of proportionality which depends on units chosen for ϕ, t and ε. In SI system the unit of flux ϕ is weber, unit of time t is second and unit of emf ε is volt and $K = 1$

$\therefore \qquad \varepsilon = -\frac{\Delta\phi}{\Delta t}$

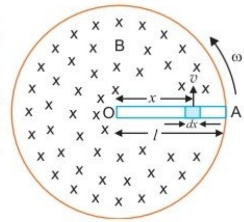
If the coil contains N turns of insulated wire, then the flux linked with each turn will be same and the emf induced in each turn will be in the same direction, hence the emfs of all turns will be added. Therefore the emf induced in the whole coil,

$$\varepsilon = -N\frac{\Delta\phi}{\Delta t} = -\frac{\Delta(N\phi)}{\Delta t}$$

$N\phi$ is called the ***effective magnetic flux*** or the ***number of flux linkages*** in ***the coil and may be denoted by*** ψ.

(b) Expression for Induced emf in a Rotating Rod

Consider a metallic rod OA of length l which is rotating with angular velocity ω in a uniform magnetic field B, the plane of rotation being perpendicular to the magnetic field. A rod may be supposed to be formed of a large number of small elements. Consider a small element of length dx at a distance x from centre. If v is the linear velocity of this element, then area swept by the element per second $= v\,dx$



The emf induced across the ends of element

$$d\varepsilon = B\frac{dA}{dt} = Bv\,dx$$

But $v = x\omega$

$\therefore$ $$d\varepsilon = B\,x\,\omega\,dx$$

$\therefore$ The emf induced across the rod

$$\varepsilon = \int_0^l B\,x\omega\,dx = B\omega\int_0^l x\,dx$$

$$= B\omega\left[\frac{x^2}{2}\right]_0^l = B\omega\left[\frac{l^2}{2} - 0\right] = \frac{B\omega l^2}{2}$$

Current induced in rod $I = \dfrac{\varepsilon}{R} = \dfrac{1}{2}\dfrac{B\omega l^2}{R}$.

If circuit is closed, power dissipated $= \dfrac{\varepsilon^2}{R} = \dfrac{B^2\omega^2 l^4}{4R}$

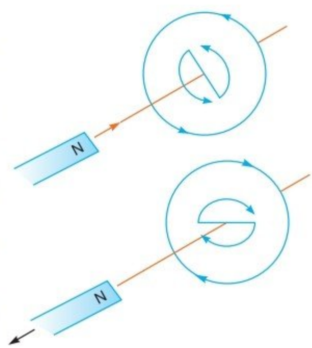
Q. 2. (a) Describe a simple experiment (or activity) to show that the polarity of emf induced in a coil is always such that it tends to produce an induced current which opposes the change of magnetic flux that produces it.

(b) The current flowing through an inductor of self inductance L is continuously increasing. Plot a graph showing the variation of

(i) Magnetic flux versus the current

(ii) Induced emf versus dI/dt

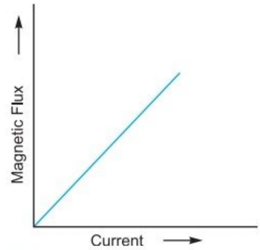
(iii) Magnetic potential energy stored versus the current. **[*CBSE Delhi 2014*]**



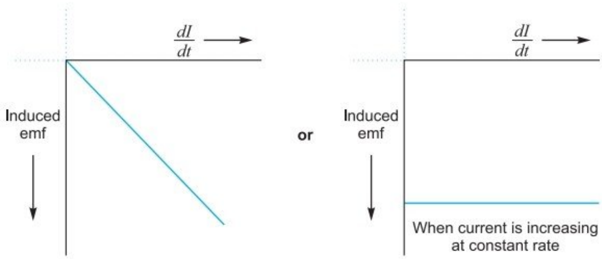
Ans. (a) When the North pole of a bar magnet moves towards the closed coil, the magnetic flux through the coil increases. This produces an induced emf which produces (or tend to produce if the coil is open) an induced current in the anti-clockwise sense. The anti-clockwise sense corresponds to the generation of North pole which opposes the motion of the approaching N pole of the magnet. The face of the coil, facing the approaching magnet, then has the same polarity as that of the approaching pole of the magnet. The induced current, therefore, is seen to oppose the change of magnetic flux that produces it.

When a North pole of a magnet is moved away from the coil, the current (I) flows in the clock-wise sense which corresponds to the generation of South pole. The induced South pole opposes the motion of the receding North pole.

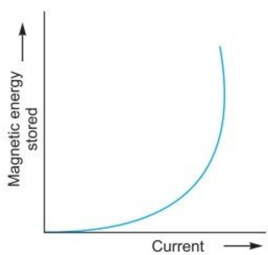
(*b*) (*i*) Magnetic flux versus the current



(*ii*) Induced emf versus dI/dt



(*iii*) Magnetic energy stored versus current



Q. 3. Derive expression for self inductance of a long air-cored solenoid of length *l*, cross-sectional area *A* and having number of turns *N*. **[*CBSE 2023* (*55/2/1*), (*55/4/1*)]**

Ans. Self Inductance of a long air-cored solenoid:

Consider a long air solenoid having 'n' number of turns per unit length. If current in solenoid is I, then magnetic field within the solenoid, $B = \mu_0 nI$ ...(*i*)

where $\mu_0 = 4\pi \times 10^{-7}$ henry/metre is the permeability of free space.

If A is cross-sectional area of solenoid, then effective flux linked with solenoid of length l is $\phi = NBA$ where $N = nl$ is the number of turns in length 'l' of solenoid.

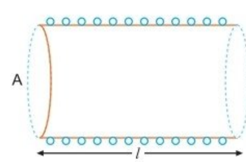
$\therefore \quad \phi = (nl\, BA)$

Substituting the value of B from (*i*)

$\therefore \quad \phi = \mu_0 n^2 AlI$

$\therefore$ Self-inductance of air solenoid

$$L = \frac{\phi}{I} = \mu_0 n^2 Al$$



If N is the total number of turns in length l then

$$n = \frac{N}{l}$$

$\therefore$ Self-inductance $L = \mu_0\left(\frac{N}{l}\right)^2 Al$

$$= \frac{\mu_0 N^2 A}{l}$$

Remark: If solenoid contains a core of ferromagnetic substance of relative permeability μ_r, then

self inductance, $L = \dfrac{\mu_r \mu_0 N^2 A}{l}$.

Q. 4. What is meant by the term 'mutual inductance' of a pair of coils? Obtain an expression for the mutual inductance of two long coaxial solenoids, each of length l but having different number of turns N_1 and N_2 and radii r_1 and r_2 ($r_2 > r_1$). *[CBSE 2023 (55/3/1)]*

OR

(a) Define mutual inductance and write its SI units. *[CBSE 2019 (55/1/1)]*

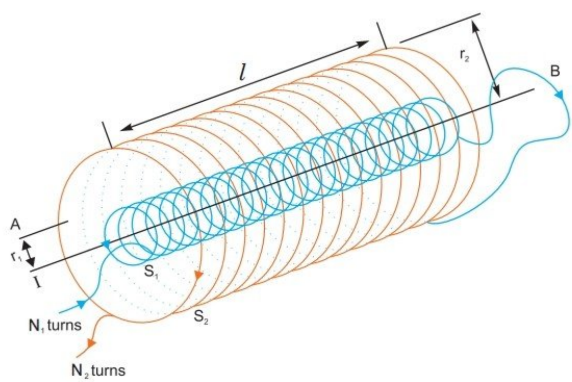
(b) Derive an expression for the mutual inductance of two long co-axial solenoids of same length wound one over the other.

(c) In an experiment, two coils C_1 and C_2 are placed close to each other. Find out the expression for the emf induced in the coil C_1 due to a change in the current through the coil C_2.

[CBSE Delhi 2015]

Ans. (a) When current flowing in one of two nearby coils is changed, the magnetic flux linked with the other coil changes; due to which an emf is induced in it (other coil). This phenomenon of electromagnetic induction is called the mutual induction. The coil, in which current is changed is called the primary coil and the coil in which emf is induced is called the secondary coil. **The SI unit of mutual inductance is henry.**

(b) Mutual inductance is numerically equal to the magnetic flux linked with one coil (secondary coil) when unit current flows through the other coil (primary coil).



Consider two long co-axial solenoids, each of length l. Let n_1 be the number of turns per unit length of the inner solenoid S_1 of radius r_1, n_2 be the number of turns per unit length of the outer solenoid S_2 of radius r_2.

Imagine a time varying current I_2 through S_2 which sets up a time varying magnetic flux ϕ_1 through S_1.

$\therefore \quad \phi_1 = M_{12}(I_2) \quad ...(i)$

where, M_{12} = Coefficient of mutual inductance of solenoid S_1 with respect to solenoid S_2

Magnetic field due to the current I_2 in S_2 is

$$B_2 = \mu_0 n_2 I_2$$

$\therefore$ Magnetic flux through S_1 is

$$\phi_1 = B_2 A_1 N_1$$

where, $N_1 = n_1 l$ and l = length of the solenoid

$$\phi_1 = (\mu_0 n_2 I_2)(\pi r_1^2)(n_1 l)$$

$$\phi_1 = \mu_0 n_1 n_2 \pi r_1^2 l I_2 \quad ...(ii)$$

From equations (*i*) and (*ii*), we get

$$M_{12} = \mu_0 n_1 n_2 \pi r_1^2 l \quad ...(iii)$$

Let us consider the reverse case.

A time varying current I_1 through S_1 develops a flux ϕ_2 through S_2.

$\therefore \quad \phi_2 = M_{21}(I_1) \quad ...(iv)$

where, M_{21} = Coefficient of mutual inductance of solenoid S_2 with respect to solenoid S_1

Magnetic flux due to I_1 in S_1 is confined solely inside S_1 as the solenoids are assumed to be very long.

There is no magnetic field outside S_1 due to current I_1 in S_1.

The magnetic flux linked with S_2 is

$\therefore \quad \phi_2 = B_1 A_1 N_2 = (\mu_0 n_1 I_1)(\pi r_1^2)(n_2 l)$

$$\phi_2 = \mu_0 n_1 n_2 \pi r_1^2 l I_1 \quad ...(v)$$

From equations (*iv*) and (*v*), we get

$$M_{21} = \mu_0 n_1 n_2 \pi r_1^2 \quad ...(vi)$$

From equations (*iii*) and (*vi*), we get

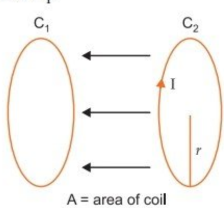
$$M_{12} = M_{21} = M = \mu_0 n_1 n_2 \pi r_1^2 l$$

We can write the above equation as

$$M = \mu_0 \left(\frac{N_1}{l}\right)\left(\frac{N_2}{l}\right) \pi r_1^2 \times l$$

$$M = \frac{\mu_0 N_1 N_2 \pi r_1^2}{l}$$

(*c*) When the current in coil C_2 changes, the flux linked with C_1 changes. This change in flux linked with C_1 induces emf in C_1.



Flux linked with C_1 = flux of C_2

$$\phi_{12} = B.A = \frac{\mu_0 I}{2r}.A$$

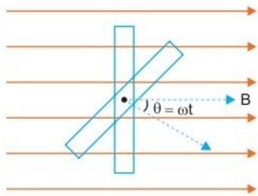
Emf induced in $C_1 = \frac{d\phi_{12}}{dt} = \frac{d}{dt}\frac{\mu_0 AI}{2r} = \frac{\boldsymbol{\mu_0 A}}{\mathbf{2r}} \times \frac{\boldsymbol{dI}}{\boldsymbol{dt}}$

Q. 5. A coil of number of turns N, area A is rotated at a constant angular speed ω, in a uniform magnetic field B and connected to a resistor R. Deduce expression for

(*i*) maximum emf induced in the coil.

(*ii*) power dissipation in the coil.

Ans. (*i*) Suppose initially the plane of coil is perpendicular to the magnetic field B. When coil rotates with angular speed ω, then after time t, the angle between magnetic field $\vec{B}$ and normal to plane of coil is $\theta = \omega t$.



$\therefore$ At this instant magnetic flux linked with the coil $\phi = BA\cos\omega t$

If coil constants, N-turns, then emf induced in the coil

$$\varepsilon = -N\frac{d\phi}{dt} = -N\frac{d}{dt}(BA\cos\omega t)$$

$$= +NBA\,\omega\sin\omega t \qquad \ldots(i)$$

$\therefore$ For maximum value of emf ε,

$\sin\omega t = 1$

$\therefore$ Maximum emf induced, $\varepsilon_{max} = \boldsymbol{NBA\,\omega}$

(*ii*) If R is resistance of coil, the current induced, $I = \frac{\varepsilon}{R}$

$\therefore$ Instantaneous power dissipated, $P = \varepsilon I = \varepsilon\left(\frac{\varepsilon}{R}\right) = \frac{\varepsilon^2}{R}$

$$= \frac{N^2B^2A^2\omega^2\sin^2\omega t}{R} \qquad \text{[using } (i)]$$

Average power dissipated in a complete cycle is obtained by taking average value of $\sin^2\omega t$ over a complete cycle which is $\frac{1}{2}$

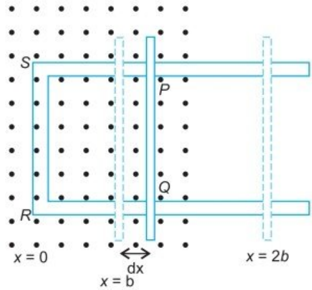
i.e., $(\sin^2\omega t)_{av} = \frac{1}{2}$

$\therefore$ Average power dissipated, $P_{av} = \frac{\boldsymbol{N^2B^2A^2\omega^2}}{\mathbf{2R}}$

Q. 6. State Faraday's law of electromagnetic induction.

Figure shows a rectangular conductor $PQRS$ in which the conductor PQ is free to move in a uniform magnetic field B perpendicular to the plane of the paper. The field extends from $x = 0$ to $x = b$ and is zero for $x > b$. Assume that only the arm PQ possesses resistance r. When the arm PQ is pulled outward from $x = 0$ to $x = 2b$ and is then moved backward to $x = 0$ with constant

speed v, obtain the expressions for the flux and the induced emf. Sketch the variations of these quantities with distance $0 \le x \le 2b$. **[CBSE (AI) 2010, (North) 2016]**



Ans. Refer to Point 3 of Points to remember.

Let length of conductor $PQ = l$

When PQ moves a small distance from x to $x + dx$ then magnetic flux linked $= BdA = Bldx$

The magnetic field is from $x = 0$ to $x = b$, to so final magnetic flux

$$= \sum Bldx = Bl \sum dx = Blx \text{ (increasing)}$$

We consider forward motion from $x = 0$ to $x = 2b$

$$\phi = Blx \;,\; 0 \le x < b$$
$$= Blb \;,\; b \le x < 2b$$

Mean magnetic flux from $x = 0$ to $x = b$ is $\frac{1}{2}Blb$

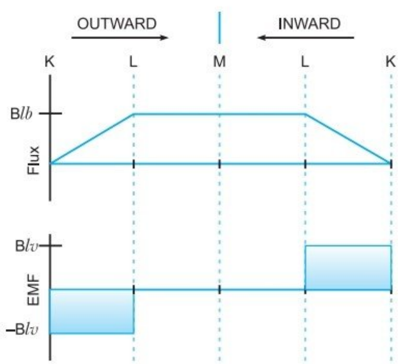
Induced emf, $\varepsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}(Bldx) = -Bl\frac{dx}{dt} = -Blv$ for, $0 \le x < b$

where $v = \frac{dx}{dt}$ velocity of arm PQ from $x = 0$ to $x = b$.

$$\varepsilon = -\frac{d}{dt}(Blb) = 0 \text{ for, } b \le x < 2b$$

During return from $x = 2b$ to $x = b$ the induced emf is zero; but now area is decreasing so magnetic flux is decreasing, and induced emf will be in opposite direction.

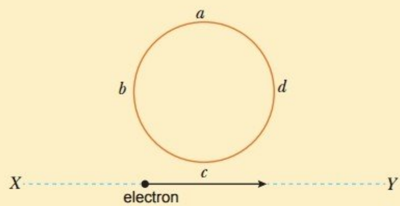
$$\varepsilon = Blv$$



Questions for Practice

1. Choose and write the correct option in the following questions.

(*i*) An electron moves on a straight line path *XY* as shown. The *abcd* is a coil adjacent to the path of electron. What will be the direction of current, if any, induced in the coil?



(*a*) The current will reverse its direction as the electron goes past the coil

(*b*) No current induced

(*c*) *abcd*

(*d*) *adcb*

(*ii*) A magnet is dropped with its north pole towards a closed circular coil placed on a table then

(*a*) looking from above, the induced current in the coil will be anti-clockwise.

(*b*) the magnet will fall with uniform acceleration.

(*c*) as the magnet falls, its acceleration will be reduced.

(*d*) no current will be induced in the coil.

(*iii*) The magnetic flux linked with a coil at any instant '*E*' is given by

$$\phi = 10t^2 - 50t + 250 \text{ Wb}$$

The induced emf at $t = 3$ s is

(*a*) – 190 V (*b*) – 10 V (*c*) 10 V (*d*) 190 V

(*iv*) A coil of area 100 cm^2 is kept at an angle of 30° with a magnetic field 10^{-1} T. The magnetic field is reduced to zero in 10^{-4} s. The induced emf in the coil is [*CBSE 2022 (55/2/4), Term-1*]

(*a*) $5\sqrt{3}$ V (*b*) $50\sqrt{3}$ V (*c*) 5.0 V (*d*) 50.0 V

(*v*) An air-cored solenoid with length 30 cm, area of cross-section 25 cm^2 and number of turns 800, carries a current of 2.5 A. The current is suddenly switched off in a brief time of 10^{-3}s. Ignoring the variation in magnetic field near the ends of the solenoid, the average back emf induced across the ends of the open switch in the circuit would be

[*CBSE Sample Paper-2022) Term-1*]

(*a*) zero (*b*) 3.125 volts (*c*) 6.54 volts (*d*) 16.74 volts

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

(a) ***Both A and R are true and R is the correct explanation of A.***

(b) ***Both A and R are true but R is not the correct explanation of A.***

(c) ***A is true but R is false.***

(d) ***A is false and R is also false.***

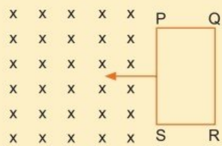
Assertion(*A*) : In the phenomenon of mutual induction, self-induction of each of the coils persists.

Reason (*R*) : Self-induction arises when strength of current in same coil changes. In mutual induction, current is changed in both individual coils.

3. Two identical coils, one of copper and the other of aluminium are rotated with the same angular speed in an external magnetic field. In which of the two coils will the induced current be more? **[*CBSE 2020 (55/3/1)*]**

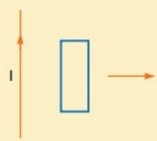
4. Predict the direction of induced current in metal rings 1 and 2 when current I in the wire is steadily decreasing.

5. The closed loop $PQRS$ is moving into a uniform magnetic field acting at right angles to the plane of the paper as shown. State the direction of the induced current in the loop. **[*CBSE (F) 2012*]**



6. A planar loop of rectangular shape is moved within the region of a uniform magnetic field acting perpendicular to its plane. What is the direction and magnitude of the current induced in it? **[*CBSE Ajmer 2015*]**

7. A rectangular loop of wire is pulled to the right, away from the long straight wire through which a steady current I flows upwards. What is the direction of induced current in the loop? **[*CBSE (F) 2010*]**



8. A rectangular loop and a circular loop are moving out of a uniform magnetic field region to a field free region with a constant velocity. In which loop do you expect the induced emf to be a constant during the passage out of the field region? The field is normal to the loop. **[*CBSE (AI) 2010*]**

9. A rectangular coil rotates in a uniform magnetic field. Obtain an expression for induced emf and current at any instant. Also find their peak values. Show the variation of induced emf versus angle of rotation (ωt) on a graph.

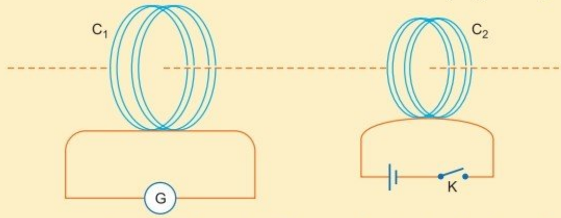
10. Two coplanar and concentric coils 1 and 2 have respectively the number of turn N_1 and N_2 of radii r_1 and r_2 ($r_2 >> r_1$) Deduce the expression for mutual inductance of this system. **[*CBSE 2020 (55/3/1)*]**

11. An iron bar falling through the hollow region of a thick cylindrical shell made of copper experiences a retarding force. What can you conclude about the nature of the iron bar ? Explain.

12. State Lenz's Law. A metallic rod held horizontally along east-west direction, is allowed to fall under gravity. Will there be an emf induced at its ends? Justify your answer. **[*CBSE Delhi 2013*]**

13. A rectangular conductor $LMNO$ is placed in a uniform magnetic field of 0.5 T. The field is directed perpendicular to the plane of the conductor. When the arm MN of length of 20 cm is moved towards left with a velocity of 10 ms^{-1}. Calculate the emf induced in the arm. Given the resistance of the arm to be 5 Ω (assuming that other arms are of negligible resistance), find the value of the current in the arm. **[*CBSE (AI) 2013*]**

14. A current is induced in coil C_1 due to the motion of current carrying coil C_2.



(*a*) Write any two ways by which a large deflection can be obtained in the galvanometer G.

(*b*) Suggest an alternative device to demonstrate the induced current in place of a galvanometer.

[*CBSE Delhi 2011*]

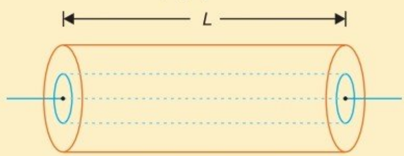
15. The closed loop (*PQRS*) of wire is moved out of a uniform magnetic field at right angles to the plane of the paper as shown in the figure. Predict the direction of the induced current in the loop. **[*CBSE (F) 2012*]**

16. Current in a circuit falls from 5.0 A to 0.0 A in 0.1 s. If an average emf of 200 V is induced, calculate the self-induction of the circuit. **[*CBSE (F) 2011*]**

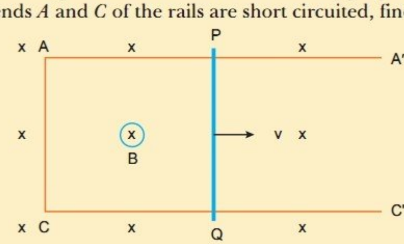
17. A long solenoid with 15 turns per cm has a small loop of area 2.0 cm^2 placed inside normal to the axis of the solenoid. The current carried by the solenoid changes steadily from 2 A to 4 A in 0.1 s, what is the induced emf in the loop while the current is changing? **[*CBSE (F) 2016*]**

18. A jet plane is travelling westward at a speed of 1800 km/h. What is the potential difference developed between the ends of a wing 25 m long? Its earth's magnetic field at the location has a magnitude of 5.0×10^{-4} T and the dip angle is 30°. **[*CBSE (AI) 2009*]**

19. Figure shows two long coaxial solenoids, each of length '*L*'. The outer solenoid has an area of cross-section A_1 and number of turns/length n_1. The corresponding values for the inner solenoid are A_2 and n_2. Write the expression for self inductance L_1, L_2 of the two coils and their mutual inductance M. Hence show that $M < \sqrt{L_1 L_2}$.



20. A conducting rod *PQ* of length 20 cm and resistance 0.1 Ω rests on two smooth parallel rails of negligible resistance *AA′* and *CC′*. It can slide on the rails and the arrangement is positioned between the poles of a permanent magnet producing uniform magnetic field $B = 0.4$ T. The rails, the rod and the magnetic field are in three mutually perpendicular directions as shown in the figure. If the ends *A* and *C* of the rails are short circuited, find the



(*i*) external force required to move the rod with uniform velocity $v = 10$ cm/s, and

(*ii*) power required to do so. **[*CBSE 2020 (55/1/1)*]**

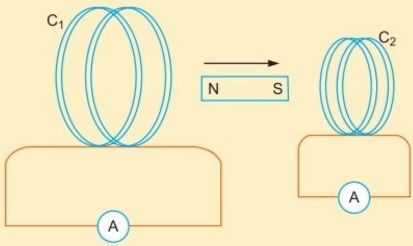
21. State Lenz's law. Illustrate, by giving an example, how this law helps in predicting the direction of the current in a loop in the presence of a changing magnetic flux.

In a given coil of self-inductance of 5 mH, current changes from 4 A to 1 A in 30 ms. Calculate the emf induced in the coil.

22. Two identical loops, one of copper and the other of aluminium, are rotated with the same angular speed in the same magnetic field. Compare (*i*) the induced emf and (*ii*) the current produced in the two coils. Justify your answer. **[*CBSE (AI) 2010*]**

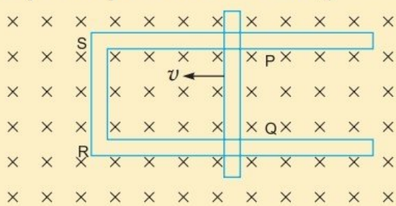
23. A wheel with 8 metallic spokes each 50 cm long is rotated with a speed of 120 rev/min in a plane normal to the horizontal component of the Earth's magnetic field. The Earth's magnetic field at the plane is 0.4 G and the angle of dip is 60°. Calculate the emf induced between the axle and the rim of the wheel. How will the value of emf be affected if the number of spokes were increased? **[*CBSE (AI) 2013*]**

24. A magnet is quickly moved in the direction indicated by an arrow between two coils C_1 and C_2 as shown in the figure. What will be the direction of induced current in each coil as seen from the magnet? Justify your answer. **[*CBSE Delhi 2011*]**



25. The currents flowing in the two coils of self-inductance $L_1 = 16$ mH and $L_2 = 12$ mH are increasing at the same rate. If the power supplied to the two coils are equal, find the ratio of (*i*) induced voltages, (*ii*) the currents and (*iii*) the energies stored in the two coils at a given instant. **[*CBSE (F) 2014*]**

26. Figure shows a rectangular loop conducting *PQRS* in which the arm *PQ* is free to move. A uniform magnetic field acts in the direction perpendicular to the plane of the loop. Arm *PQ* is moved with a velocity v towards the arm *RS*. Assuming that the arms *QR*, *RS* and *SP* have negligible resistances and the moving arm *PQ* has the resistance *r*, obtain the expression for (*i*) the current in the loop (*ii*) the force and (*iii*) the power required to move the arm *PQ*. **[*CBSE Delhi 2013*]**



Answers

1. (*i*) (*a*) (*ii*) (*a*) (*iii*) (*b*) (*iv*) (*c*) (*v*) (*d*)

2. (*i*) (*b*)

13. 1 V, 0.2 A **16.** 4H **17.** 7.5 μV **18.** 3.1 V

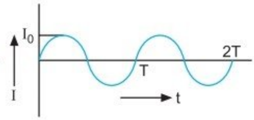
20. (*i*) 6.4×10^{-3} N (*ii*) 6.4×10^{-4} W **21.** 0.5 V **23.** 3.14×10^{-5} V

25. (*i*) $\frac{4}{3}$ (*ii*) $\frac{3}{4}$ (*iii*) $\frac{3}{4}$

7 Alternating Current

POINTS TO REMEMBER

1. Alternating Current



Alternating current is the one which changes in magnitude continuously and in direction periodically. The maximum value of current is called **current-amplitude or peak value of current**.

It is expressed as

$$I = I_0 \sin \omega t$$

Similarly alternating voltage (or emf) is

$$V = V_0 \sin \omega t$$

2. Mean and RMS Value of Alternating Currents

The mean value of alternating current over complete cycle is **zero**.

i.e., $(I_{mean})_{full\ cycle} = 0$

For half cycle,

$$(I_{mean})_{half\ cycle} = \frac{2I_0}{\pi} = 0.636 I_0$$

$$V_{av} = \frac{2V_0}{\pi} = 0.636\, V_0$$

An electrical device reads root mean square value as

$$I_{rms} = \sqrt{(I^2)_{mean}} = \frac{I_0}{\sqrt{2}} = 0.707 I_0\,;\, V_{rms} = \frac{V_0}{\sqrt{2}} = 0.707\, V_0$$

3. Phase Difference between Voltage and Current

In a circuit having a reactive component, there is always a phase difference between applied voltage and the alternating current.

If $E = E_0 \sin \omega t$

Current, $I = I_0 \sin (\omega t + \phi)$

where ϕ is the phase difference between voltage and current.

4. Impedance and Reactance

Impedance: The opposition offered by an electric circuit to an alternating current is called impedance. It is denoted as Z. Its unit is ohm.

$$Z = \frac{V}{I} = \frac{V_0}{I_0} = \frac{V_{rms}}{I_{rms}}$$

Reactance: The opposition offered by inductance and capacitance or both in *ac* circuit is called reactance. It is denoted by X_C or X_L.

The opposition due to inductor alone is called the inductive reactance while that due to capacitance alone is called the capacitive reactance.

Inductive reactance, $\quad X_L = \omega L$

Capacitive reactance, $\quad X_C = \dfrac{1}{\omega C}$

5. Purely Resistive Circuit

If a circuit contains pure resistance, then phase difference $\phi = 0$ *i.e.*, current and voltage are in the same phase.

Phase diagram

Impedance, $Z = R$

6. Purely Inductive Circuit

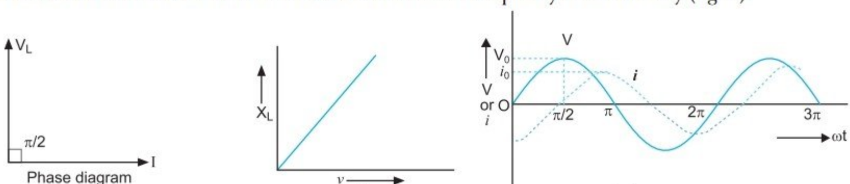
If a circuit contains pure inductance, then $\phi = -\dfrac{\pi}{2}$, *i.e.*, current lags behind the applied voltage by an angle $\dfrac{\pi}{2}$.

i.e., $\quad$ If $V = V_0 \sin \omega t$

$$I = I_0 \sin\left(\omega t - \frac{\pi}{2}\right)$$

In this case inductive reactance, $X_L = \omega L$

The inductive reactance increases with the increase of frequency of AC linearly (fig. b).



(a) (b) (c)

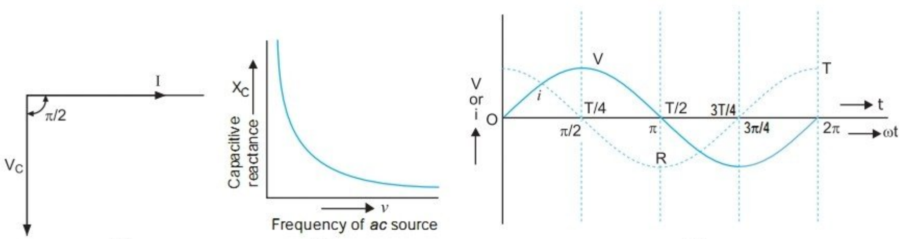
7. Purely Capacitive Circuit

If circuit contains pure capacitance, then $\phi = \dfrac{\pi}{2}$, *i.e.*, current leads the applied voltage by angle $\dfrac{\pi}{2}$ *i.e.*,

$V = V_0 \sin\omega t, I = I_0 \sin\left(\omega t + \dfrac{\pi}{2}\right)$

Capacitance reactance, $X_C = \dfrac{1}{\omega C}$

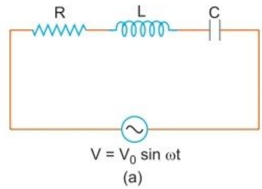
Clearly capacitance reactance (X_C) is inversely proportional to the frequency ν (fig. b).



(a) (b) (c)

8. Series *LCR* Circuit

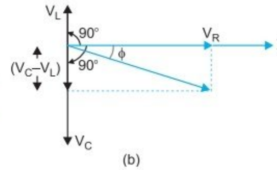
If a circuit contains inductance L, capacitance C and resistance R, connected in series to an alternating voltage $V = V_0 \sin \omega t$



then impedance $Z = \sqrt{R^2 + (X_C - X_L)^2}$

and phase $\qquad \phi = \tan^{-1} \dfrac{X_C - X_L}{R}$

Net voltage $\qquad V = \sqrt{V_R^2 + (V_C - V_L)^2}$



9. Resonant Circuits

Series *LCR* circuit: In series *LCR* circuit, when phase (ϕ) between current and voltage is zero, the circuit is said to be resonant circuit. In resonant circuit $X_C = X_L$ or $\dfrac{1}{\omega C} = \omega L$

$$\Rightarrow \qquad \omega = \frac{1}{\sqrt{LC}}$$

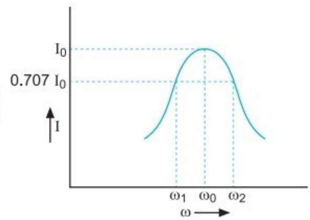
Resonant angular frequency $\omega_r = \dfrac{1}{\sqrt{LC}}$

(linear) frequency, $\nu_r = \dfrac{\omega_r}{2\pi} = \dfrac{1}{2\pi\sqrt{LC}}$

At resonant frequency $\phi = 0$, $V = V_R$

Quality factor (Q)

The quality factor (Q) of series *LCR* circuit is defined as the ratio of the resonant frequency to frequency band width of the resonant curve.



$$Q = \frac{\omega_r}{\omega_2 - \omega_1} = \frac{\omega_r L}{R}$$

Clearly, smaller the value of R, larger is the quality factor and sharper the resonance. Thus quality factor determines the nature of sharpness of resonance. It has no unit.

10. Power Dissipation in AC Circuit is

$$P = V_{rms} I_{rms} \cos\phi = \frac{1}{2} V_0 I_0 \cos\phi$$

where $\cos\phi = \dfrac{R}{Z}$ is the power factor.

For maximum power

$$\cos\phi = 1 \quad \text{or} \quad Z = R$$

i.e., circuit is purely resistive.

For minimum power

$$\cos\phi = 0 \quad \text{or} \quad R = 0$$

i.e., circuit should be free from ohmic resistance.

Power loss, $P = I^2 R$

11. Wattless Current

In purely inductive or purely capacitive circuit, power loss is zero. In such a circuit, current flowing is called wattless current.

$$I_{wattless} = I \sin\phi = I\left(\frac{X_C}{Z}\right) = I\left(\frac{X_L}{Z}\right)$$

12. AC Generator

It is a device used to convert mechanical energy into electrical energy and is based on the phenomenon of electromagnetic induction. If a coil of N turns, area A is rotated at frequency ν in uniform magnetic field of induction B, then motional emf in coil (if initially it is perpendicular to field) is

$$\varepsilon = NBA\,\omega \sin \omega t \text{ with } \omega = 2\pi\nu$$

Peak emf, $\varepsilon_0 = NBA\,\omega$

13. Transformer

A transformer is a device which converts low *ac* voltage into high *ac* voltage and vice versa. It works on the principle of mutual induction. If N_p and N_S are the number of turns in primary and secondary coils, V_P and I_P are voltage and current in primary coil, then voltage (V_S) and current (I_S) in secondary coil will be

$$V_S = \left(\frac{N_S}{N_P}\right)V_P \quad \text{and} \quad I_S = \left(\frac{N_P}{N_S}\right)I_P$$

Step up transformer increases the voltage while step down transformer decreases the voltage.

In step up transformer $V_S > V_P$ so $N_S > N_P$

In step down transformer $V_S < V_P$ so $N_S < N_P$

Energy Losses and Efficiency of a Transformer

(*i*) **Copper Losses:** When current flows in primary and secondary coils, heat is produced. The power loss due to Joule heating in coils will be i^2R where R is resistance and i is the current.

(*ii*) **Iron Losses (Eddy currents):** The varying magnetic flux produces eddy currents in iron-core, which leads to dissipation of energy in the core of transformer. This is minimised by using a laminated iron core or by cutting slots in the plate.

(*iii*) **Flux Leakage:** In actual transformer, the coupling of primary and secondary coils is never perfect, *i.e.*, the whole of magnetic flux generated in primary coil is never linked up with the secondary coil. This causes loss of energy.

(*iv*) **Hysteresis Loss:** The alternating current flowing through the coils magnetises and demagnetises the iron core repeatedly. The complete cycle of magnetisation and demagnetisation is termed as hysteresis. During each cycle some energy is dissipated. However, this loss of energy is minimised by choosing silicon-iron core having a thin hysteresis loop.

(*v*) **Humming Losses:** Due to the passage of alternating current, the core of transformer starts vibrating and produces humming sound. Due to this a feeble part of electrical energy is lost in the form of humming sound.

On account of these losses the output power obtained across secondary coil is less than input power given to primary. Therefore, the efficiency of a practical transformer is always less than 100%.

$$\text{Percentage efficiency of transformer} = \frac{\text{output power obtained from secondary}}{\text{input power given to primary}} \times 100\%$$

$$= \frac{V_S i_S}{V_P i_P} \times 100\%$$

Multiple Choice Questions

Choose and write the correct option(s) in the following questions.

1. **If the *rms* current in a 50 Hz *ac* circuit is 5 A, the value of the current 1/300 seconds after its value becomes zero is** [*NCERT Exemplar*]

   (*a*) $5\sqrt{2}$ A (*b*) $5\sqrt{\dfrac{3}{2}}$ A (*c*) 5/6 A (*d*) $5/\sqrt{2}$ A

2. **An alternating current generator has an internal resistance R_g and an internal reactance X_g. It is used to supply power to a passive load consisting of a resistance R_g and a reactance X_L. For maximum power to be delivered from the generator to the load, the value of X_L is equal to** [*NCERT Exemplar*]

   (*a*) zero (*b*) X_g (*c*) $-X_g$ (*d*) R_g

3. **When a voltage measuring device is connected to *ac* mains, the meter shows the steady input voltage of 220 V. This means** [*NCERT Exemplar*]

   (*a*) input voltage cannot be *ac* voltage, but a *dc* voltage.

   (*b*) maximum input voltage is 220 V.

   (*c*) the meter reads not V but $<V^2>$ and is calibrated to read $\sqrt{<V^2>}$.

   (*d*) the pointer of the meter is stuck by some mechanical defect.

4. **To reduce the resonant frequency in an *LCR* series circuit with a generator** [*NCERT Exemplar*]

   (*a*) the generator frequency should be reduced.

   (*b*) another capacitor should be added in parallel to the first.

   (*c*) the iron core of the inductor should be removed.

   (*d*) dielectric in the capacitor should be removed.

5. **Electrical energy is transmitted over large distances at high alternating voltages. Which of the following statements is (are) correct?** [*NCERT Exemplar*]

   (*a*) For a given power level, there is a lower current.

   (*b*) Lower current implies less power loss.

   (*c*) Transmission lines can be made thinner.

   (*d*) It is easy to reduce the voltage at the receiving end using step-down transformers.

6. **In a pure inductive circuit, the current**

   (*a*) lags behind the applied emf by an angle π

   (*b*) lags behind the applied emf by an angle $\pi / 2$

   (*c*) leads the applied emf by an angle $\pi / 2$

   (*d*) and applied emf are in same phase

7. **When an *ac* voltage of 220 V is applied to the capacitor *C*** [*NCERT Exemplar*]

   (*a*) the maximum voltage between plates is 220 V.

   (*b*) the current is in phase with the applied voltage.

   (*c*) the charge on the plates is in phase with the applied voltage.

   (*d*) power delivered to the capacitor is zero.

8. **In an *ac* circuit, voltage V and current i are given by**

   $V = 100 \sin 100\, t$ **volt**

   $i = 100 \sin (100t + \pi/3)$ **mA**

   The power dissipated in the circuit is

   (*a*) 10^4W (*b*) 10 W (*c*) 2.5 W (*d*) 5 W

9. **Which of the following combinations should be selected for better tuning of an *LCR* circuit used for communication?** **[*NCERT Exemplar*]**

(*a*) $R = 20\ \Omega, L = 1.5\ \text{H}, C = 35\ \mu\text{F}$
(*b*) $R = 25\ \Omega, L = 2.5\ \text{H}, C = 45\ \mu\text{F}$
(*c*) $R = 15\ \Omega, L = 3.5\ \text{H}, C = 30\ \mu\text{F}$
(*d*) $R = 25\ \Omega, L = 1.5\ \text{H}, C = 45\ \mu\text{F}$

10. **The output of a step-down transformer is measured to be 24 V when connected to a 12 watt light bulb. The value of the peak current is** **[*NCERT Exemplar*]**

(*a*) $1/\sqrt{2}$ A (*b*) $\sqrt{2}$ A (*c*) 2 A (*d*) $2\sqrt{2}$ A

11. **The selectivity of a series *LCR* ac circuit is large, when** **[*CBSE 2020 (55/5/1)*]**

(*a*) L is large and R is large
(*b*) L is small and R is small
(*c*) L is large and R is small
(*d*) $L = R$

12. **The phase difference between the current and the voltage in series *LCR* circuit at resonance is** **[*CBSE 2020 (55/5/2)*]**

(*a*) π (*b*) $\pi/2$ (*c*) $\pi/3$ (*d*) zero

13. **An alternating current is given by $i = i_1 \cos \omega t + i_2 \sin \omega t$. The rms current is given by**

(*a*) $\dfrac{i_1 + i_2}{\sqrt{2}}$ (*b*) $\dfrac{i_1 - i_2}{\sqrt{2}}$ (*c*) $\sqrt{\dfrac{i_1^2 + i_2^2}{2}}$ (*d*) $\dfrac{i_1 i_2}{\sqrt{2}}$

14. **An alternating voltage source of variable angular frequency 'ω' and fixed amplitude '*V*' is connected in series with a capacitance *C* and electric bulb of resistance *R* (inductance zero). When 'ω' is increased** **[*CBSE Sample Paper-2022, Term-1*]**

(*a*) the bulb glows dimmer
(*b*) the bulb glows brighter
(*c*) net impedance of the circuit remains unchanged
(*d*) total impedance of the circuit increases

15. **The rms current in a circuit connected to a 50 Hz ac source is 15A. The value of the current in the circuit $\left(\dfrac{1}{600}\right)$s after the instant the current is zero, is** **[*CBSE 2022 (55/2/4), Term-1*]**

(*a*) $\dfrac{15}{\sqrt{2}}$A (*b*) $15\sqrt{2}$A (*c*) $\dfrac{\sqrt{2}}{15}$A (*d*) 8 A

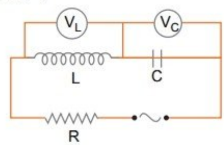
16. **When an alternating voltage $E = E_o \sin \omega t$ is applied to a circuit, a current $I = I_o \sin\left(\omega t + \dfrac{\pi}{2}\right)$ flows through it. The average power dissipated in the circuit is** **[*CBSE 2022 (55/2/4), Term-1*]**

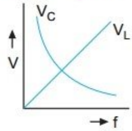
(*a*) $E_{rms} \cdot I_{rms}$ (*b*) $E_o I_o$ (*c*) $\dfrac{E_o I_o}{\sqrt{2}}$ (*d*) zero

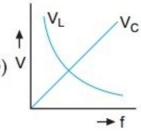
17. **The voltage across a resistor, an inductor, and a capacitor connected in series to an ac source are 20 V, 15 V and 30 V respectively. The resultant voltage in the circuit is** **[*CBSE 2022 (55/2/4), Term-1*]**

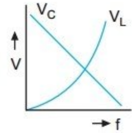
(*a*) 5 V (*b*) 20 V (*c*) 25 V (*d*) 65 V

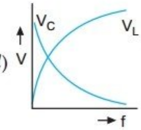
18. **A series *LCR* circuit is shown in figure. The source frequency *f* is varied, but the current is kept unchanged. Which of the curves shows changes of V_C and V_L with frequency?**



(*a*)


(*b*)


(*c*)


(*d*)


19. **A 300 Ω resistor and a capacitor of $\left(\frac{25}{\pi}\right)\mu F$ are connected in series to a 200 V – 50 Hz *ac* source. The current in the circuit is** **[*CBSE 2022 (55/2/4), Term-1*]**

(*a*) 0.1 A (*b*) 0.4 A (*c*) 0.6 A (*d*) 0.8 A

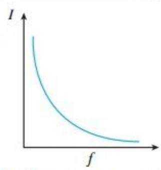
20. **The core of a transformer is laminated to reduce the effect of** **[*CBSE Sample Paper-2022, Term-1*]**

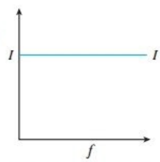
(*a*) flux leakage (*b*) copper loss (*c*) hysteresis loss (*d*) eddy current

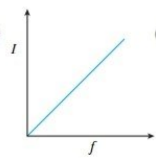
21. **Which among the following is not a cause for power loss in a transformer?** **[*CBSE Sample Paper-2022, Term-1)*]**

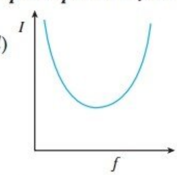
(*a*) Eddy currents are produced in the soft iron core of a transformer.
(*b*) Electric flux sharing is not properly done in primary and secondary coils.
(*c*) Humming sound produced in the transformers due to magnetostriction.
(*d*) Primary coil is made up of a very thick copper wire.

22. **Which of the following graphs represent the variation of current (I) with frequency (f) in an AC circuit containing a pure capacitor?** **[*CBSE Sample Paper-2022, Term-1*]**

(*a*)


(*b*)


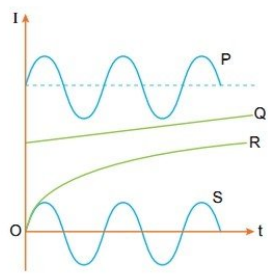
(*c*)


(*d*)


23. **An inductor, a capacitor and a resistor are connected in series across an ac source of voltage. If the frequency of the source is decreased gradually the reactance of** **[*CBSE 2023 (55/3/1)*]**

(*a*) both the inductor and the capacitor decreases.
(*b*) inductor decreases and the capacitor increases.
(*c*) both the inductor and the capacitor increases.
(*d*) inductor increases and the capacitor decreases.

24. **The figure shows variation of current (I) with time (t) in four devices P, Q, R and S. The device in which an alternating current flows is** **[*CBSE 2023 (55/4/1)*]**



(*a*) P (*b*) Q (*c*) R (*d*) S

25. **An *ac* voltage $v = v_0 \sin \omega t$ is applied to a series combination of a resistor R and an element X. The instantaneous current in the circuit is $I = I_0 \sin\left(\omega t + \frac{\pi}{4}\right)$. Then which of the following is correct?** **[*CBSE 2023 (55/4/1)*]**

(*a*) X is a capacitor and $X_C = \sqrt{2}\ R$ (*b*) X is an inductor and $X_L = R$
(*c*) X is an inductor and $X_L = \sqrt{2}\ R$ (*d*) X is a capacitor and $X_C = R$

26. The instantaneous values of EMF and the current in a series AC circuit are $E = E_0 \sin \omega t$ and $I = I_0 \sin (\omega t + \pi/3)$ respectively, then it is **[*CBSE Sample Paper-2022, Term-1*]**

(*a*) necessarily a *RL* circuit
(*b*) necessarily a *RC* circuit
(*c*) necessarily a *LCR* circuit
(*d*) can be *RC* or *LCR* circuit

Answers

1. (*b*)	**2.** (*c*)	**3.** (*c*)	**4.** (*b*)	**5.** (*a*), (*b*), (*d*)	**6.** (*b*)	**7.** (*c*), (*d*)
8. (*c*)	**9.** (*c*)	**10.** (*a*)	**11.** (*c*)	**12.** (*d*)	**13.** (*c*)	**14.** (*b*)
15. (*a*)	**16.** (*d*)	**17.** (*c*)	**18.** (*a*)	**19.** (*b*)	**20.** (*d*)	**21.** (*d*)
22. (*c*)	**23.** (*b*)	**24.** (*a*)	**25.** (*d*)	**26.** (*d*)		

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(*a*) ***Both A and R are true and R is the correct explanation of A.***
(*b*) ***Both A and R are true but R is not the correct explanation of A.***
(*c*) ***A is true but R is false.***
(*d*) ***A is false and R is also false.***

1. Assertion(*A*) : An alternating current of frequency 50 Hz becomes zero, 100 times in one second.
Reason (*R*) : Alternating current changes direction and becomes zero twice in a cycle.

2. Assertion(*A*) : Capacitor serves as a block for *DC* and offers an easy path to *AC*.
Reason (*R*) : Capacitive reactance is inversely proportional to frequency.

3. Assertion(*A*) : When capacitive reactance is smaller than the inductive reactance in *LCR* circuit, *emf* leads the current.
Reason (*R*) : The phase angle is the angle between the alternating *emf* and alternating current of the circuit.

4. Assertion(*A*) : Transformers are used only in alternating current source not in direct current.
Reason (*R*) : Only a.c. can be stepped up or down by means of transformers. **[*AIIMS 2009*]**

5. Assertion(*A*) : An inductance and a resistance are connected in series with an AC circuit. In this circuit the current and the potential difference across the resistance lags behind potential difference across the inductance by an angle $\pi/2$.
Reason (*R*) : In *LR* circuit voltage leads the current by phase angle which depends on the value of inductance and resistance both.

6. Assertion(*A*) : In series *LCR* resonance circuit, the impedance is equal to the ohmic resistance.
Reason (*R*) : At resonance, the inductive reactance exceeds the capacitive reactance.

7. Assertion(*A*) : An alternating current does not show any magnetic effect.
Reason (*R*) : Alternating current does not vary with time.

8. Assertion(*A*) : In series *LCR*-circuit, the resonance occurs at one frequency only.
Reason (*R*) : At resonance, the inductive reactance is equal and opposite to the capacitive reactance.

9. Assertion(*A*) : A step-up transformer cannot be used as a step-down transformer.
Reason (*R*) : A transformer works only in one direction. **[*CBSE 2022 (55/2/4), Term-1*]**

10. **Assertion (*A*)** : It is advantageous to transmit electric power at high voltage.
Reason (*R*) : High voltage implies high current. *[AIIMS 2010]*

Answers

1. (*a*) **2.** (*a*) **3.** (*b*) **4.** (*a*) **5.** (*b*) **6.** (*c*) **7.** (*d*)
8. (*a*) **9.** (*d*) **10.** (*b*)

Case-based/Passage-based Questions

Read the paragraph given below and answer the questions that follow:

Electrical Energy Transmission and Distribution:

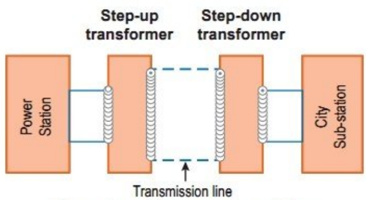


Figure: Long distance power transmissions

The large-scale transmission and distribution of electrical energy over long distances is done with the use of transformers. The voltage output of the generator is stepped-up. It is then transmitted over long distances to an area sub-station near the consumers. There the voltage is stepped down. It is further stepped down at distributing sub-stations and utility poles before a power supply of 240 V reaches our homes. *[CBSE Sample Paper-2022, Term-I, Modified]*

(*i*) Which of the following statement is true?

(*a*) Energy is created when a transformer steps up the voltage.
(*b*) A transformer is designed to convert an AC voltage to DC voltage.
(*c*) Step–up transformer increases the power for transmission.
(*d*) Step–down transformer decreases the AC voltage.

(*ii*) If the secondary coil has a greater number of turns than the primary,

(*a*) the voltage is stepped-up ($V_s > V_p$) and arrangement is called a step-up transformer
(*b*) the voltage is stepped-down ($V_s < V_p$) and arrangement is called a step-down transformer
(*c*) the current is stepped-up ($I_s > I_p$) and arrangement is called a step-up transformer
(*d*) the current is stepped-down ($I_s < I_p$) and arrangement is called a step-down transformer

OR

We need to step-up the voltage for power transmission, so that

(*a*) the current is reduced and consequently, the I^2R loss is cut down
(*b*) the voltage is increased , the power losses are also increased
(*c*) the power is increased before transmission is done
(*d*) the voltage is decreased so V^2/R losses are reduced

(*iii*) A power transmission line feeds input power at 2300 V to a step down transformer with its primary windings having 4000 turns. The number of turns in the secondary in order to get output power at 230 V are

(*a*) 4 (*b*) 40
(*c*) 400 (*d*) 4000

(iv) The metal/alloy that is more suitable for making cores of transformers is

(a) steel (b) soft iron (c) copper (d) brass

Explanations

(i) (d) In step down transformer,

$$V_S < V_P \quad \text{and} \quad I_S > I_P.$$

So, step-down transformer decreases the *ac* voltage.

(ii) (a) In step up transformer,

$$V_S > V_P \quad \text{and} \quad I_P > I_S$$

and, $$\frac{N_S}{N_P} = \frac{V_S}{V_P} = \frac{I_P}{I_S} > 1$$

i.e., if number of turns in secondary coil are more than the number of turns in primary coil, then voltage is increased, and hence they are called step-up transformers.

OR

(a) Current is reduced if voltage is stepped up so consequently I^2R (copper losses) are cut down.

(iii) (c) Given, $E_P = 2300$ V

$E_S = 230$ V

$N_P = 4000$

then, $$\frac{E_P}{E_S} = \frac{N_P}{N_S}$$

$$\Rightarrow \quad \frac{2300}{230} = \frac{4000}{N_S}$$

$$\Rightarrow \quad N_S = 400$$

So, number of turns in secondary are 400.

(iv) (b) Soft iron because it reduced the hysteresis loss.

CONCEPTUAL QUESTIONS

Q. 1. Define capacitor reactance. Write its SI units? **[*CBSE Delhi 2015*]**

Ans. The imaginary/virtual resistance offered by a capacitor to the flow of an alternating current is called capacitor reactance, $X_C = \dfrac{1}{\omega C}$. Its SI unit is ohm.

Q. 2. Explain why current flows through an ideal capacitor when it is connected to an *ac* source but not when it is connected to a *dc* source in a steady state. **[*CBSE (East) 2016*]**

Ans. For *ac* source, circuit is complete due to the presence of displacement current in the capacitor. For steady *dc*, there is no displacement current, therefore, circuit is not complete.

Mathematically, Capacitive reactance $X_C = \dfrac{1}{2\pi\nu C} = \dfrac{1}{\omega C}$

So, capacitor allows easy path for *ac* source.

For *dc*, $\nu = 0$, so X_c = infinity,

So capacitor blocks *dc*.

Q. 3. Define 'quality factor' of resonance in series *LCR* circuit. What is its SI unit? **[*CBSE Delhi 2016*]**

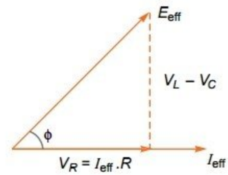
Ans. The quality factor (Q) of series *LCR* circuit is defined as the ratio of the resonant frequency to frequency band width of the resonant curve.

$$Q = \frac{\omega_r}{\omega_2 - \omega_1} = \frac{\omega_r L}{R}$$

Clearly, smaller the value of R, larger is the quality factor and sharper the resonance. Thus quality factor determines the nature of sharpness of resonance.
It has no units.

Q. 4. In a series *LCR* circuit, $V_L = V_C \neq V_R$.
What is the value of power factor for this circuit? [*CBSE Panchkula 2015*]

Ans. Power factor,



$$\cos\phi = \frac{V_R}{\sqrt{V_R^2 + (V_L - V_C)^2}}$$

Since $\quad V_L = V_C$; $\cos\phi = \dfrac{V_R}{V_R} = 1$

The value of power factor is 1.

Q. 5. The power factor of an *ac* circuit is 0.5. What is the phase difference between voltage and current in this circuit? [*CBSE (F) 2015, (South) 2016*]

Ans. Power factor between voltage and current is given by $\cos\phi$, where ϕ is phase difference

$$\cos\phi = 0.5 = \frac{1}{2} \Rightarrow \quad \phi = \cos^{-1}\left(\frac{1}{2}\right) = \frac{\pi}{3}$$

Q. 6. What is wattless current? [*CBSE Delhi 2011, Chennai 2015*]

Ans. When pure inductor and/or pure capacitor is connected to ac source, the current flows in the circuit, but with no power loss; the phase difference between voltage and current is $\frac{\pi}{2}$. Such a current is called the wattless current.

Q. 7. What is the impedance of a capacitor of capacitance *C* in an *ac* circuit using source of frequency *n* Hz? [*CBSE 2020 (55/2/1)*]

Ans.

Impedance of a capacitor of capacitance $C = \frac{1}{\omega C}$.
$\omega = 2\pi n$.
$\therefore$ impedance $= \frac{1}{2\pi n C}$.

[*Topper's Answer 2020*]

Q. 8. A light bulb and a solenoid are connected in series across an ac source of voltage. Explain, how the glow of the light bulb will be affected when an iron rod is inserted in the solenoid. [*CBSE (F) 2017*]

Ans. When iron rod is inserted in the coil, the inductance of coil increases; so impedance of circuit increases and hence, current in circuit $I = \dfrac{V}{\sqrt{R^2 + (\omega L)^2}}$ decreases. Consequently, the glow of bulb decreases.

Q. 9. Why is the use of *ac* voltage preferred over *dc* voltage? Give two reasons. [*CBSE (AI) 2014*]

Ans. (*i*) The generation of *ac* is more economical than *dc*.

(*ii*) Alternating voltage can be stepped up or stepped down as per requirement during transmission from power generating station to the consumer.

(*iii*) Alternating current in a circuit can be controlled by using wattless devices like the choke coil.

(*iv*) Alternating voltages can be transmitted from one place to another, with much lower energy loss in the transmission line.

Q. 10. What is the average value of *ac* voltage

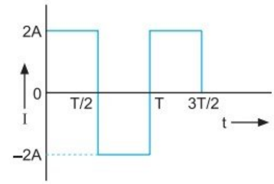
$$V = V_0 \sin \omega t$$

over the time interval $t = 0$ to $t = \frac{\pi}{\omega}$. [*HOTS*]

Ans. $V_{av} = \dfrac{\int_0^{\pi/\omega} V dt}{\int_0^{\pi/\omega} dt} = \dfrac{\int_0^{\pi/\omega} V_0 \sin \omega t \, dt}{[t]_0^{\pi/\omega}} = \dfrac{V_0\left\{-\dfrac{\cos \omega t}{\omega}\right\}_0^{\pi/\omega}}{\pi/\omega} = -\dfrac{V_0}{\pi}[\cos\pi - \cos 0] = \dfrac{2V_0}{\pi}$

Q. 11. What is the rms value of alternating current shown in figure? **[*HOTS*]**

Ans. In given *ac*, there are identical positive and negative half cycles, so the mean value of current is zero; but the rms value is not zero.



$$(I^2)_{mean} = \frac{\int_0^T I^2 dt}{\int_0^T dt} = \frac{\int_0^{T/2} (2)^2 dt + \int_{T/2}^{T} (-2)^2 dt}{T} = \frac{\int_0^T 4dt}{T} = 4$$

$$I_{rms} = \sqrt{4} = \mathbf{2\ A}$$

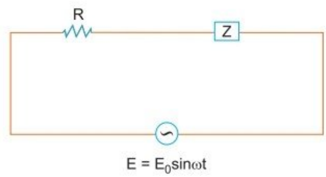
Very Short Answer Questions

Each of the following questions are of 2 marks.

Q. 1. An alternating voltage $E = E_0 \sin \omega t$ is applied to a circuit containing a resistor R connected in series with a black box. The current in the circuit is found to be $I = I_o \sin(\omega t + \pi/4)$.

(*i*) State whether the element in the black box is a capacitor or inductor.

(*ii*) Draw the corresponding phasor diagram and find the impedance in terms of R.



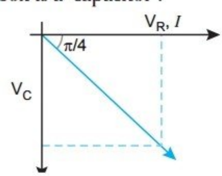
Ans. (*i*) As the current leads the voltage by $\dfrac{\pi}{4}$, the element used in black box is a 'capacitor'.

(*ii*) Here, $\tan\dfrac{\pi}{4} = V_C/V_R \quad \Rightarrow \quad 1 = \dfrac{V_C}{V_R}$

$\Rightarrow \quad V_C = V_R \quad \Rightarrow \quad X_C = R$

$\therefore$ Impedance $Z = \sqrt{(X_C)^2 + R^2} = \sqrt{R^2 + R^2} = \sqrt{2R^2}$

$\therefore \; Z = \sqrt{2}\,\mathbf{R}$



Q.2. The coil of an ac generator consists of 100 turns of wire, each of area 0.5m^2. The resistance of the wire is 100 Ω. The coil is rotating in a magnetic field of 0.8 T perpendicular to its axis of rotation, at a constant angular speed of 60 radian per second. Calculate the maximum emf generated and power dissipated in the coil. **[*CBSE 2023 (55/2/1)*]**

Ans. Given, $N = 100, A = 0.5 \text{ m}^2, R = 100\ \Omega, B = 0.8\text{T}, \omega = 60 \text{ rad } s^{-1}$

εmf generate,

$$\varepsilon_0 = NA\omega B = 100 \times 0.5 \times 60 \times 0.8$$
$$= 2400 \text{ volt}$$

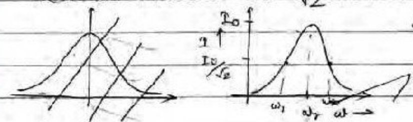
Power dissipated, $P = \dfrac{\varepsilon_{rms}^2}{R} = \dfrac{\left(\dfrac{2400}{\sqrt{2}}\right)^2}{100} = \mathbf{28.8\ kW}$

Q. 3. **(a) Explain the term 'sharpness of resonance' in *ac* circuit.**

(b) In a series *LCR* circuit, $V_L = V_C \neq V_R$. What is the value of power factor for this circuit? [*CBSE 2020 (55/2/1)*]

Ans.

(a) • Sharpness of resonance' or 'Q-factor of AC circuit is defined as the ratio of the resonant $\overset{\text{angular}}{\text{frequency}}$ to the difference in angular frequencies of two sides in which the current in the circuit ~~which~~ reduces to $\frac{1}{\sqrt{2}}$ times its maximum value.



∴ by the figure, sharpness of resonance $= \dfrac{\omega_r}{\omega_2 - \omega_1}$

(b) In a series LCR circuit, $V_L = V_C \neq V_R$.

∴ power factor = 1

[*Topper's Answer 2020*]

Q. 4. **A circular coil of radius 10 cm and 20 turns is rotated about its vertical diameter with angular speed of 50 rad s^{-1} in a uniform horizontal magnetic field of $3{\cdot}0 \times 10^{-2}$ T.**

(i) Calculate the maximum and average emf induced in the coil.

(ii) If the coil forms a closed loop of resistance 10 Ω, calculate the maximum current in the coil and the average power loss due to Joule heating. [*CBSE 2019 (55/4/1)*]

Ans. (i) Here, $r = 10$ cm, N = 20 turns, $\omega = 50$ rad s^{-1}

$$B = 3.0 \times 10^{-2}\ \text{T}$$

$$\varepsilon_0 = \text{NBA}\omega$$

$$= 20 \times 3 \times 10^{-2} \times \pi\,(10 \times 10^{-2})^2 \times 50 \qquad \tfrac{1}{2}$$

$$= 0.942 \text{ volt}$$

$$\varepsilon_{AV} = 0, \text{ over a cycle} \qquad \tfrac{1}{2}$$

(ii) $$i_0 = \frac{e_0}{R} = \frac{0.942}{10}$$

$$= 0.094 \text{ A} \qquad \tfrac{1}{2}$$

$$P = \frac{1}{2}\,\varepsilon_0 \times I_0$$

$$= \frac{1}{2} \times 0.942 \times 0.094$$

$$= 0.045 \text{ watt.} \qquad \tfrac{1}{2}$$

[*CBSE Marking Scheme 2019 (55/4/1)*]

Q. 5. **Calculate the quality factor of a series *LCR* circuit with $L = 2.0$ H, $C = 2$ μF and $R = 10$ Ω. Mention the significance of quality factor in *LCR* circuit.** [*CBSE (F) 2012*]

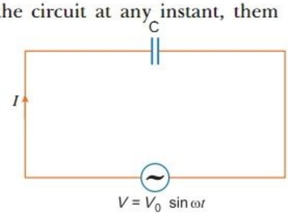
Ans. We have, $$Q = \frac{1}{R}\sqrt{\frac{L}{C}} = \frac{1}{10}\sqrt{\frac{2}{2 \times 10^{-6}}} = \mathbf{100}$$

It signifies the sharpness of resonance.

Q. 6. **An *ac* source of emf $V = V_0 \sin \omega t$ is connected to a capacitor of capacitance *C*. Deduce the expression for the current (*I*) flowing in it. Plot the graph of (i) *V* vs. ωt, and (ii) *I* vs. ωt.**

[*CBSE 2020 (55/2/1), 2023 (55/3/1)*]

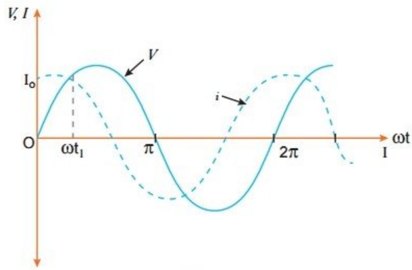
Ans. Let q be the charge on capacitor (C) and I, the current in the circuit at any instant, them instantaneous current is given by



$$I = \frac{dq}{dt} = \frac{d}{dt} CV_0 \sin \omega t = \omega CV_0 \cos \omega t$$

$$= I_0 \cos \omega t = I_0 \sin\left(\omega t + \frac{\pi}{2}\right) \quad \text{where,} \quad I_0 = \frac{V_0}{(1/\omega C)}$$

Graphs for (*i*) and (*ii*)



Q. 7. Both alternating current and direct current are measured in amperes. But how is the ampere defined for an alternating current? **[*NCERT Exemplar*]**

Ans. An *ac* current changes direction with the source frequency and the attractive force would average to zero. Thus, the *ac* ampere must be defined in terms of some property that is independent of the direction of current. Joule's heating effect is such property and hence it is used to define rms value of *ac*.

Q. 8. A 60 W load is connected to the secondary of a transformer whose primary draws line voltage. If a current of 0.54 A flows in the load, what is the current in the primary coil? Comment on the type of transformer being used. **[*NCERT Exemplar*]**

Ans. Here, $P_L = 60$ W, $I_L = 0.54$ A

$$V_L = \frac{60}{0.54} = 111.1 \text{ V}$$

The transformer is step-down and have $\frac{1}{2}$ input voltage. Hence

$$I_P = \frac{1}{2} \times I_L = \frac{1}{2} \times 0.54 = \mathbf{0.27\ A.}$$

Q. 9. Explain why the reactance provided by a capacitor to an alternating current decreases with increasing frequency. **[*NCERT Exemplar*]**

Ans. A capacitor does not allow flow of direct current through it as the resistance across the gap is infinite. When an alternating voltage is applied across the capacitor plates, the plates are alternately charged and discharged. The current through the capacitor is a result of this changing voltage (or charge). Thus, a capacitor will pass more current through it if the voltage is changing at a faster rate, *i.e.*, if the frequency of supply is higher. This implies that the reactance offered by a capacitor is less with increasing frequency; it is given by $1/\omega C$.

Q. 10. Explain why the reactance offered by an inductor increases with increasing frequency of an alternating voltage. **[*NCERT Exemplar*]**

Ans. An inductor opposes flow of current through it by developing an induced emf according to Lenz's law. The induced voltage has a polarity so as to maintain the current at its present value. If the current is decreasing, the polarity of the induced emf will be so as to increase the current and vice versa. Since the induced emf is proportional to the rate of change of current, it will provide greater reactance to the flow of current if the rate of change is faster, *i.e.*, if the frequency is higher. The reactance of an inductor, therefore, is proportional to the frequency, being given by ωL.

Q. 11. **(a) A 44 mH inductor is connected to 220 V, 50 Hz *ac* supply. Determine the rms value of current in the circuit.** **[*NCERT*] [*CBSE (AI) 2013, 2012*]**

(b) What is the net power absorbed by the circuit in a complete cycle?

Ans. (*a*) Given $L = 44$ mH$= 44 \times 10^{-3}$ H, $V_{rms} = 220$ V, $\nu = 50$ Hz

Inductive reactance of current $X_C = \omega L$

$\therefore$ RMS value of current,

$$I_{rms} = \frac{V_{rms}}{\omega L} = \frac{V_{rms}}{2\pi\nu L}$$

$$= \frac{220}{2 \times \left(\frac{22}{7}\right) \times 50 \times 44 \times 10^{-3}}$$

$$= \frac{220 \times 7 \times 10^3}{2 \times 22 \times 50 \times 44} = \frac{700}{44} = \mathbf{15.9\ A}$$

(*b*) We know, $P = V_{rms} . I_{rms} . \cos\phi$

In pure inductor circuit $\phi = \frac{\pi}{2}$ radians

$$\Rightarrow \qquad \cos\frac{\pi}{2} = 0$$

As such net power consumed $= V_{rms} I_{rms} \cos\frac{\pi}{2} = \mathbf{0}$

Short Answer Questions

Each of the following questions are of 3 marks.

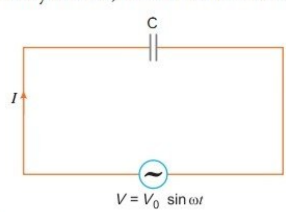
Q. 1. **Show that the current leads the voltage in phase by $\pi/2$ in an *ac* circuit containing an ideal capacitor.** **[*CBSE (F) 2014*]**

Ans. The instantaneous voltage,

$$V = V_0 \sin \omega t \qquad \ldots(i)$$

Let q be the charge on capacitor and I, the current in the circuit at any instant, then instantaneous potential difference,

$$V = \frac{q}{C} \qquad \ldots(ii)$$



From (*i*) and (*ii*), we get

$$\frac{q}{C} = V_0 \sin\omega t \Rightarrow q = CV_0 \sin\omega t$$

The instantaneous current,

$$I = \frac{dq}{dt} = \frac{d}{dt}(CV_0 \sin\omega t) = CV_0 \frac{d}{dt}(\sin\omega t) = CV_0 \omega \cos\omega t$$

$$I = \frac{V_0}{1/\omega C}\cos\omega t$$

$$I = I_0 \sin\left(\omega t + \frac{\pi}{2}\right)$$

Hence, the current leads the applied voltage in phase by $\pi/2$.

Q. 2. In a series *LCR* circuit, obtain the conditions under which (*i*) the impedance of the circuit is minimum, and (*ii*) wattless current flows in the circuit. **[*CBSE (F) 2014*]**

Ans. (*i*) Impedance of series *LCR* circuit is given by

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

For the impedance, Z to be minimum,

$$X_L = X_C$$

(*ii*) Power, $P = V_{rms} I_{rms} \cos\phi$

When $\phi = \dfrac{\pi}{2}$

Power $= V_{rms} I_{rms} \cos\dfrac{\pi}{2} = 0$

Therefore, wattless current flows when the impedance of the circuit is purely inductive or purely capacitive.

In another way we can say, for wattless current to flow, circuit should not have any ohmic resistance ($R = 0$).

Q. 3. State the underlying principle of a transformer. How is the large scale transmission of electric energy over long distances done with the use of transformers? **[*CBSE (AI) 2012*]**

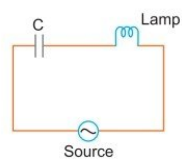
Ans. The principle of transformer is based upon the principle of mutual induction which states that due to continuous change in the current in the primary coil an emf gets induced across the secondary coil. At the power generating station, the step up transformers step up the output voltage which reduces the current through the cables and hence reduce resistive power loss. Then, at the consumer end, a step down transformer steps down the voltage.

Hence, the large scale transmission of electric energy over long distances is done by stepping up the voltage at the generating station to minimise the power loss in the transmission cables.

Q. 4. An electric lamp connected in series with a capacitor and an *ac* source is glowing with of certain brightness. How does the brightness of the lamp change on reducing the (*i*) capacitance and (*ii*) frequency? **[*CBSE Delhi 2010, (North) 2016*]**

Ans. (*i*) When capacitance is reduced, capacitive reactance $X_C = \dfrac{1}{\omega C}$ increases, hence impedance of circuit

$$Z = \sqrt{R^2 + X_C^2}$$



increases and so current $I = \dfrac{V}{Z}$ decreases. As a result the brightness of the bulb is reduced.

(*ii*) When frequency decreases; capacitive reactance $X_C = \dfrac{1}{2\pi\nu C}$ increases and hence impedance of circuit increases, so current decreases. As a result brightness of bulb is reduced.

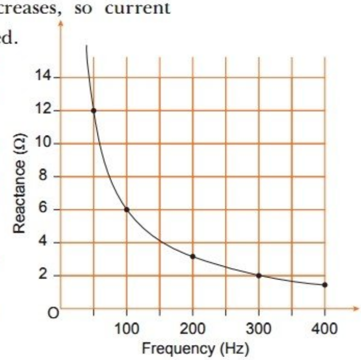
Q. 5. The figure shows the graphical variation of the reactance of a capacitor with frequency of ac source.

(*a*) Find the capacitance of the capacitor.

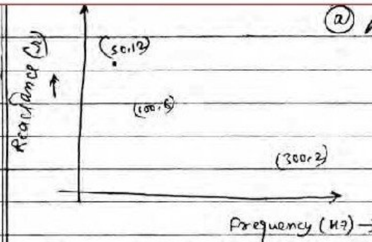
(*b*) An ideal inductor has the same reactance at 100 Hz frequency as the capacitor has at the same frequency. Find the value of inductance of the inductor.

(*c*) Draw the graph showing the variation of the reactance of this inductor with frequency.

[*CBSE 2020 (55/2/1)*]



Ans.

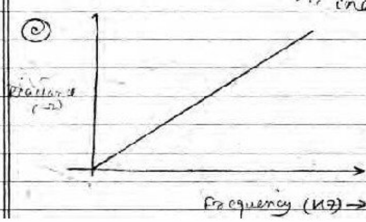


(a) We know, for AC source,
capacitor reactance, $X_C = \frac{1}{\omega C}$
$\Rightarrow X_C = \frac{1}{2\pi f C}$.
f = Frequency (in Hz)

Here, a point on the graph is (100, 6).
$\therefore$, when $f = 100$, $X_C = 6$.
$\Rightarrow 6 = \frac{1}{2\pi \times 100 \times C} \Rightarrow 2\pi \times 100 \times C = \frac{1}{6}$
$\Rightarrow C = \frac{1}{1200\pi}$
$\therefore$, $C = \frac{7}{1200 \times 22}$ F $= 0.0265 \times 10^{-2}$ F
$= 2.65 \times 10^{-4}$ F.
$\therefore$ required capacitance $= 2.65 \times 10^{-4}$ F. (Ans)

(b) At 100 Hz, ~~frequen~~ ~~inductance~~ reactance of inductor $= 6\ \Omega$.
We know, reactance $X_L = \omega L$
L is inductance of inductor.
$\therefore$, $6 = 2\pi \times 100 \times L \Rightarrow L = \frac{6}{200\pi}$ H
$\therefore$, $L = \frac{3 \times 7}{100 \times 22} = \frac{21}{22 \times 100}$ H $= 0.954 \times 10^{-2}$ H
$\therefore$ inductance $= 0.954 \times 10^{-2}$ H (Ans)

(c)



$\because X_L = \omega L = 2\pi f L$.
$\therefore$, $X_L = f \cdot 2\pi L$.
$\therefore$ the graph is a straight line passing through origin.

[Topper's Answer 2020]

Q. 6. A capacitor of unknown capacitance, a resistor of 100 Ω and an inductor of self inductance $L = \left(\frac{4}{\pi^2}\right)$ henry are connected in series to an *ac* source of 200 V and 50 Hz. Calculate the value of the capacitance and impedance of the circuit when the current is in phase with the voltage. Calculate the power dissipated in the circuit. **[*CBSE South 2016*]**

Ans. Capacitance, $C = \frac{1}{L\omega^2} = \frac{1}{\frac{4}{\pi^2}(2\pi \times 50)^2}\text{F} = \frac{1}{40000}\text{F} = \mathbf{2.5 \times 10^{-5}\ F}$

Since V and I are in same phase. then $Z = R = \mathbf{100\ \Omega}$

Power dissipated $= \frac{E_{rms}^2}{2} = \frac{(200)^2}{100}\text{W} = \mathbf{400\ W}$

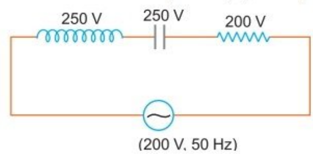
Q. 7. A series *LCR* circuit is connected to an *ac* source (200 V, 50 Hz). The voltages across the resistor, capacitor and inductor are respectively 200 V, 250 V and 250 V.

(*i*) The algebraic sum of the voltages across the three elements is greater than the voltage of the source. How is this paradox resolved?

(*ii*) Given the value of the resistance of *R* is 40 Ω, calculate the current in the circuit.

[*CBSE (F) 2013*]

Ans. (*i*) From given parameters



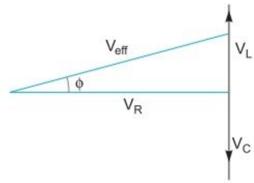
$V_R = 200$ V, $V_L = 250$ V and $V_C = 250$ V

V_{eff} should be given as

$$V_{eff} = V_R + V_L + V_C = 200\text{ V} + 250\text{ V} + 250\text{ V} = 700\text{ V}$$

However, $V_{eff} > 200$ V of the *ac* source.

This paradox can be solved only by using phaser diagram, as given below:



$$(V_{eff}) = \sqrt{V_R^2 + (V_L - V_C)^2}$$

Since $V_L = V_C$ so $V_{eff} = V_R = 200$ V

(*ii*) Given $R = 40\ \Omega$, so current in the *LCR* circuit.

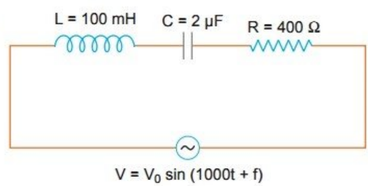
$$I_{eff} = \frac{V_{eff}}{R} \qquad [X_L = X_C \quad \text{or} \quad Z = R]$$

$$= \frac{200}{40} = \mathbf{5\ A}$$

Q. 8. (*i*) Find the value of the phase difference between the current and the voltage in the series *LCR* circuit shown below. Which one leads in phase: current or voltage?

(*ii*) Without making any other change, find the value of the additional capacitor, C_1, to be connected in parallel with the capacitor *C*, in order to make the power factor of the circuit unity. **[*CBSE Delhi 2017, Allahabad 2015*]**

Ans. (*i*) Inductive reactance,



$$X_L = \omega L = (1000 \times 100 \times 10^{-3})\ \Omega = 100\ \Omega$$

Capacitive reactance,

$$X_C = \frac{1}{\omega C} = \left(\frac{1}{1000 \times 2 \times 10^{-6}}\right) \Omega = 500\ \Omega$$

Phase angle,

$$\tan\phi = \frac{X_L - X_C}{R}$$

$$\tan\phi = \frac{100 - 500}{400} = -1$$

$$\phi = -\frac{\pi}{4}$$

As $X_C > X_L$, (phase angle is negative), hence current leads voltage.

(*ii*) To make power factor unity

$X_{C'} = X_L$ (where C' = net capacitance of parallel combination)

$$\frac{1}{\omega C'} = 100$$

$\therefore \quad C' = 10 \times 10^{-6}$ F $= 10\ \mu$F

$\because \quad C' = C + C_1$

$\Rightarrow \quad 10 = 2 + C_1 \qquad \Rightarrow \mathbf{C_1 = 8\ \mu F}$

Q. 9. A series *LCR* circuit with $R = 20\ \Omega$, $L = 2\ H$ and $C = 50\ \mu F$ is connected to a 200 volts ac source of variable frequency. What is (*i*) the amplitude of the current, and (*ii*) the average power transferred to the circuit in one complete cycle, at resonance? (*iii*) Calculate the potential drop across the capacitor. **[*CBSE 2023 (55/4/1)*]**

Ans. (*i*) At resonance, $Z = R$

$$I_{rms} = \frac{V_{rms}}{Z} = \frac{200}{20} = 10\ \text{A}$$

Amplitude of the current, $I_0 = \sqrt{2} \times I_{rms}$

$$= 1.414 \times 10 = \mathbf{14.14\ A}$$

(*ii*) Average power transferred to the circuit in one complete cycle at resonance,

$$P = I_{rms}^2 R = (10)^2 \times 20$$

$$= \mathbf{2000\ W}$$

(*iii*) Resonant frequency,

$$\omega_r = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{2 \times 50 \times 10^{-6}}} = 100\ \text{rad/s}$$

$$X_C = \frac{1}{\omega_r C} = \frac{1}{100 \times 50 \times 10^{-6}}$$

Voltage across capacitor,

$$V_C = I_{rms} X_C = 10 \times \frac{1}{100 \times 50 \times 10^{-6}} = \mathbf{2000\ V}$$

Q. 10. A series *CR* circuit with $R = 200\ \Omega$ and $C = (50/\pi)\ \mu F$ is connected across an ac source of peak voltage $\varepsilon_0 = 100$ V and frequency $\nu = 50$ Hz. Calculate (*a*) impedance of the circuit (*Z*), (*b*) phase angle (ϕ), and (*c*) voltage across the resistor. **[*CBSE 2023 (55/2/1)*]**

Ans. (*a*) Given, $R = 200\ \Omega$,

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi\nu C} = \frac{1}{2\pi \times 50 \times \frac{50}{\pi} \times 10^{-6}} = 200\ \Omega$$

Impudence, $Z = \sqrt{R^2 + X_C^2}$

$$Z = \sqrt{(200)^2 + (200)^2} = \mathbf{200\sqrt{2}\ \Omega}$$

(*b*) Phase angle, $\tan\phi = \frac{X_C}{R} = \frac{200}{200} = 1 \quad \Rightarrow \quad \phi = \mathbf{45°}$ or $\mathbf{\frac{\pi}{4}}$ **rad**

(*c*) $\varepsilon_{rms} = \frac{\varepsilon_0}{\sqrt{2}} = \frac{100}{\sqrt{2}}\text{V}$

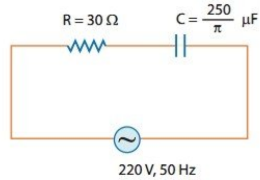
and $I_{rms} = \frac{\varepsilon_{rms}}{Z} = \frac{\frac{100}{\sqrt{2}}}{200\sqrt{2}} = \frac{1}{4}\text{A}$

So, $V_R = I_{rms} R = \frac{1}{4} \times 200 = \mathbf{50\ V.}$

Q. 11. A resistor of 30 Ω and a capacitor of $\frac{250}{\pi}\ \mu F$ are connected in series to a 200 V, 50 Hz *ac* source. Calculate (*i*) the current in the circuit, and (*ii*) voltage drops across the resistor and the capacitor (*iii*) Is the algebraic sum of these voltages more than the source voltage? If yes, solve the paradox. **[*CBSE 2023 (55/4/1)*]**

Ans. (*i*) capacitive reactant,

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi\nu C}$$
$$= \frac{1}{2\pi \times 50 \times \frac{250}{\pi} \times 10^{-6}}$$
$$= 40\ \Omega$$



Impedance of the circuit, $Z = \sqrt{R^2 + X_C^2}$

$$= \sqrt{(30)^2 + (40)^2} = 50\ \Omega$$

So, current in the circuit, $I_{\text{rms}} = \frac{E_{rms}}{Z} = \frac{200}{50} = \mathbf{4\ A}$

(*ii*) Voltage across resistor, $V_R = I_{\text{rms}} R = 4 \times 30 = \mathbf{120\ V}$

Voltage across capacitor, $V_C = I_{\text{rms}} X_C = 4 \times 40 = \mathbf{160\ V}$

(*iii*) The algebraic sum of voltages across the combination is

$$V_{rms} = V_R + V_C = 120 + 160 = 280\ \text{V}$$

While V_{rms} of the source is 200 V. Yes, the voltages across the combination is more than the voltage of the source. The voltage across the resistor and capacitor are not in phase.

This paradox can be resolved as when the current passes through the capacitor, it leads the voltage V_C by phase $\frac{\pi}{2}$. So voltage of the source can be given as,

$$V_{rms} = \sqrt{V_R^2 + V_C^2} = \sqrt{(120)^2 + (160)^2}$$
$$= \sqrt{14400 + 25600} = 200\ \text{V}.$$

Q. 12. The primary coil of an ideal step up transformer has 100 turns and transformation ratio is also 100. The input voltage and power are 220 V and 1100 W respectively. Calculate

(*a*) the number of turns in the secondary coil.

(*b*) the current in the primary coil.

(*c*) the voltage across the secondary coil.

(*d*) the current in the secondary coil.

(*e*) the power in the secondary coil. **[*CBSE Delhi 2016*]**

Ans. (*a*) Transformation ratio $r = \frac{\text{Number of turns in secondary coil}\,(N_S)}{\text{Number of turns in primary coil}\,(N_P)}$

Given $N_P = 100$, $r = 100$

$\therefore$ Number of turns in secondary coil, $N_S = rN_P = 100 \times 100 = \mathbf{10{,}000}$

(*b*) Input voltage $V_P = 220$ V, Input power $P_{in} = 1100$ W

Current in primary coil $I_p = \frac{P_{in}}{V_P} = \frac{1100}{220} = \mathbf{5\ A}$

(*c*) Voltage across secondary coil (V_S) is

$\therefore \quad V_S = rV_P = 100 \times 220 = 22{,}000\ \text{V} = \mathbf{22\ kV}$ $\quad \left(r = \frac{V_S}{V_P}\right)$

(*d*) Current in secondary coil (I_S),

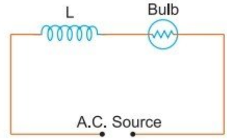
$\therefore \quad I_S = \frac{I_P}{r} = \frac{5}{100} = \mathbf{0.05\ A}$ $\quad \left(r = \frac{I_P}{I_S}\right)$

(*e*) Power in secondary coil, $P_{out} = V_S I_S = 22 \times 10^3 \times 0.05 = \mathbf{1100\ W}$

Obviously power in secondary coil is same as power in primary. This means that the transformer is ideal, *i.e.*, there are no energy losses.

Q. 13. An inductor L of reactance X_L is connected in series with a bulb B to an *ac* source as shown in figure. Explain briefly how does the brightness of the bulb change when (*i*) number of turns of the inductor is reduced (*ii*) an iron rod is inserted in the inductor and (*iii*) a capacitor of reactance $X_C = X_L$ is included in the circuit.

[*CBSE Delhi 2014, 2015*]



Ans. Brightness of the bulb depends on square of the I_{rms} (*i.e.*, I^2_{rms})

Impedance of the circuit, $Z = \sqrt{R^2 + (\omega L)^2}$ and

Current in the circuit, $I = \dfrac{V}{Z}$

(*i*) When the number of turns in the inductor is reduced, the self inductance of the coil decreases; so impedance of circuit reduces and so current in the circuit $\left(I = \dfrac{E}{Z}\right)$ increases. Thus, the brightness of the bulb increases.

(*ii*) When iron (being a ferromagnetic substance) rod is inserted in the coil, its inductance increases and in turn, impedance of the circuit increases. As a result, a larger fraction of the applied ac voltage appears across the inductor, leaving less voltage across the bulb. Hence, brightness of the bulb decreases.

(*iii*) When capacitor of reactance $X_C = X_L$ is introduced, the net reactance of circuit becomes zero, so impedance of circuit decreases; it becomes $Z = R$; so current in circuit increases; hence brightness of bulb increases. Thus brightness of bulb in both cases increases.

Q. 14. A capacitor (C) and resistor (R) are connected in series with an *ac* source of voltage of frequency 50 Hz. The potential difference across C and R are respectively 120 V, 90 V, and the current in the circuit is 3 A. Calculate (*i*) the impedance of the circuit (*ii*) the value of the inductance, which when connected in series with C and R will make the power factor of the circuit unity.

[*CBSE 2019 (55/2/1)*]

Ans. As from relation,

$$R = \frac{V_R}{I_R} = \frac{90}{3} = 30\,\Omega$$

$$X_C = \frac{V_C}{I_C} = \frac{120}{3} = 40\,\Omega$$

(*i*) Impedance, $Z = \sqrt{R^2 + X_C^2}$

$$= \sqrt{30^2 + 40^2} = \mathbf{50\,\Omega}$$

(*ii*) As power factor = 1

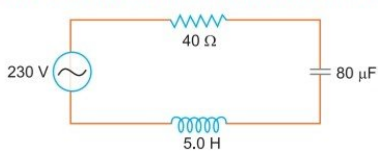
Now, $X_L = X_C$

$$2\pi\nu L = 40$$

$$100\pi L = 40$$

$$\therefore \quad L = \mathbf{\frac{2}{5\pi}\,H}.$$

Q. 15. The figure shows a series *LCR* circuit connected to a variable frequency 230 *V* source.



(*a*) Determine the source frequency which drives the circuit in resonance.

(*b*) **Calculate the impedance of the circuit and amplitude of current at resonance.**

(*c*) **Show that potential drop across *LC* combination is zero at resonating frequency.**

[*CBSE 2019 (55/2/1)*]

Ans. (*a*) $\omega = \dfrac{1}{\sqrt{LC}} = \dfrac{1}{\sqrt{5\times 80\times 10^{-6}}} = \dfrac{1}{\sqrt{400\times 10^{-6}}}$

$\omega = \dfrac{1000}{20} = 50 \text{ rad/s} \Rightarrow f = \dfrac{\omega}{2\pi} = \dfrac{50}{2\pi} = \dfrac{\mathbf{25}}{\pi}\ \mathbf{Hz}$

(*b*) At resonance, $Z = R = \mathbf{40\ \Omega}$

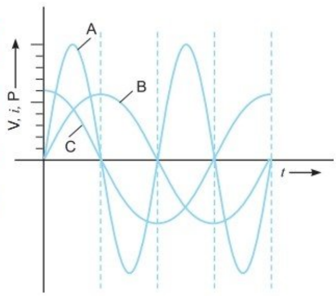
$I_{max} = \dfrac{230\sqrt{2}}{R} = \dfrac{230\sqrt{2}}{40} = \mathbf{8.1\ A}$

(*c*) $V_C = I_{max}X_C = \dfrac{230\sqrt{2}}{40} \times \dfrac{1}{50\times 80\times 10^{-6}} = 2025\text{ V} \qquad [\because X_C = \dfrac{1}{\omega C}]$

$V_L = I_{max}X_L = \dfrac{230\sqrt{2}}{40} \times 50 \times 5 = 2025\text{ V} \quad [\because X_L = \omega L]$

Hence, $V_C - V_L = 0$

Q. 16. A device '*X*' is connected to an *ac* source. The variation of voltage, current and power in one complete cycle is shown in the figure.



(*a*) **Which curve shows power consumption over a full cycle?**

(*b*) **What is the average power consumption over a cycle?**

(*c*) **Identify the device '*X*'.** **[*NCERT Exemplar*]**

Ans. (*a*) *A*

(*b*) Zero

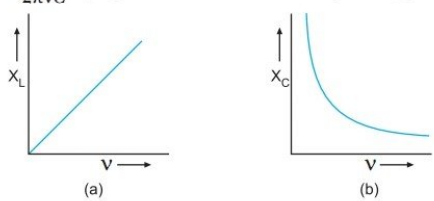
(*c*) *L* or *C* or *LC* Series combination of *L* and *C*

Q. 17. (*i*) **Draw the graphs showing variation of inductive reactance and capacitive reactance with frequency of applied *ac* source.**

(*ii*) **Can the voltage drop across the inductor or the capacitor in a series *LCR* circuit be greater than the applied voltage of the *ac* source? Justify your answer.** **[*HOTS*]**

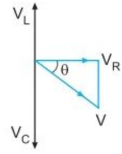
Ans. (*i*) (*a*) $X_L = \omega L = 2\pi\nu L$; graph of X_L and ν is a straight line

(*b*) $X_C = \dfrac{1}{\omega C} = \dfrac{1}{2\pi\nu C}$, graph of X_C and ν is a rectangular hyperbola as shown in fig.



(a) (b)

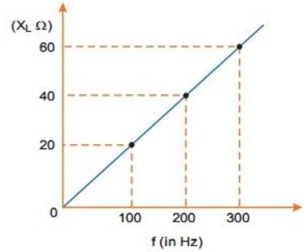
(*ii*) Yes; because $V = \sqrt{V_R^2 + (V_C - V_L)^2}$;



As V_C and V_L have opposite faces, V_C or V_L may be greater than V.

The situation may be as shown in figure where $V_C > V$.

Q. 18. The variation of inductive reactance (X_L) of an inductor with the frequency (*f*) of the *ac* source of 100 V and variable frequency is shown in the fig.



(*i*) **Calculate the self-inductance of the inductor.**

(*ii*) **When this inductor is used in series with a capacitor of unknown value and a resistor of 10 Ω at 300 s^{-1}, maximum power dissipation occurs in the circuit. Calculate the capacitance of the capacitor.** [*CBSE 2020 (55/5/1)*]

Ans. As we know, $X_L = 2\pi f L$ ½

$$L = \frac{X_L}{2\pi f} = \frac{40}{2\pi \times 200} = 0.1/\pi \text{ henry} = 0.032\text{H}$$ ½

Maximum power dissipation takes place at resonance, ½

$$\nu = \frac{1}{2\pi\sqrt{LC}}$$ ½

$$\Rightarrow \quad C = \frac{1}{L \times 300^2 \times 4\pi^2}\text{F}$$ ½

$$\therefore \quad C = \frac{\pi}{0.1 \times 9 \times 10^4 \times 4\pi^2}\text{F} = 8.8\mu\text{F}$$ ½

[*CBSE Marking Scheme 2020 (55/5/1)*]

Long Answer Questions

Each of the following questions are of 5 marks.

Q. 1. Explain the term inductive reactance. Show graphically the variation of inductive reactance with frequency of the applied alternating voltage.

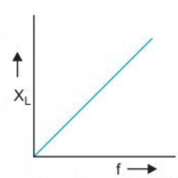
An *ac* voltage $V = V_0 \sin \omega t$ is applied across a pure inductor of inductance *L*. Find an expression for the current *i*, flowing in the circuit and show mathematically that the current flowing through it lags behind the applied voltage by a phase angle of $\frac{\pi}{2}$. Also draw (*i*) phasor diagram (*ii*) graphs of *V* and *i* versus ωt for the circuit. [*CBSE East 2016*]

Ans. **Inductive Reactance:** The opposition offered by an inductor to the flow of alternating current through it is called the inductive reactance. It is denoted by X_L. Its value is $X_L. = \omega L = 2\pi f L$

where L is inductance and f is the frequency of the applied voltage.

Obviously $\quad X_L \propto f$

Thus, the graph between X_L and frequency f is linear (as shown in fig.).



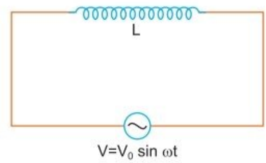
Phase Difference between Current and Applied Voltage in Purely Inductive circuit :

AC circuit containing pure inductance: Consider a coil of self-inductance L and negligible ohmic resistance. An alternating potential difference is applied across its ends. The magnitude and direction of *ac* changes periodically, due to which there is a continual change in magnetic flux linked with the coil. Therefore according to Faraday's law, an induced emf is produced in the coil, which opposes the applied voltage. As a result the current in the circuit is reduced. That is ***inductance acts like a resistance in ac circuit***. The instantaneous value of alternating voltage applied

$$V = V_0 \sin \omega t \quad \ldots(i)$$

If i is the instantaneous current in the circuit and $\frac{di}{dt}$ the rate of change of current in the circuit at that instant, then instantaneous induced emf

$$\varepsilon = -L\frac{di}{dt}$$



(a)

According to Kirchhoff's loop rule

$$V + \varepsilon = 0 \Rightarrow V - L\frac{di}{dt} = 0$$

or $$V = L\frac{di}{dt} \text{ or } \frac{di}{dt} = \frac{V}{L}$$

or $$\frac{di}{dt} = \frac{V_0 \sin\omega t}{L} \text{ or } di = \frac{V_0 \sin\omega t}{L}dt$$

Integrating with respect to time 't',

$$i = \frac{V_0}{L}\int \sin \omega t\, dt = \frac{V_0}{L}\left\{-\frac{\cos\omega t}{\omega}\right\} = -\frac{V_0}{\omega L}\cos\omega t = -\frac{V_0}{\omega L}\sin\left(\frac{\pi}{2}-\omega t\right)$$

or $$i = \frac{V_0}{\omega L}\sin\left(\omega t - \frac{\pi}{2}\right) \quad \ldots(ii)$$

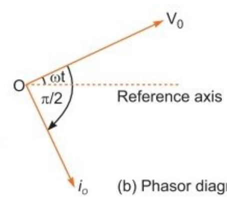
This is required expression for current

or $$i = i_0 \sin\left(\omega t - \frac{\pi}{2}\right) \quad \ldots(iii)$$

where $$i_0 = \frac{V_0}{\omega L}$$

is the peak value of alternating current

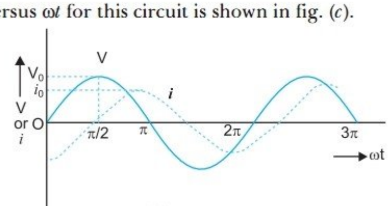
Also comparing (*i*) and (*iii*), we note that current lags behind the applied voltage by an angle $\frac{\pi}{2}$ (Fig. *b*).



(b) Phasor diagram

Phasor diagram: The phasor diagram of circuit containing pure inductance is shown in Fig. (*b*).

Graphs of V and I versus ωt for this circuit is shown in fig. (*c*).



(c)

Q. 2. (*a*) What is impedance?

(*b*) A series *LCR* circuit is connected to an *ac* source having voltage $V = V_0 \sin \omega t$. Derive expression for the impedance, instantaneous current and its phase relationship to the applied voltage. Find the expression for resonant frequency.

[*CBSE Delhi 2010, 2023(55/1/1)*]

OR

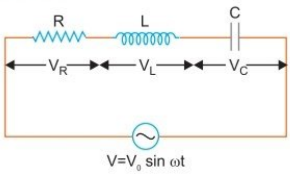
(a) An *ac* source of voltage $V = V_0 \sin \omega t$ is connected to a series combination of L, C and R. Use the phasor diagram to obtain expressions for impedance of the circuit and phase angle between voltage and current. Find the condition when current will be in phase with the voltage. What is the circuit in this condition called?

(b) In a series LR circuit $X_L = R$ and power factor of the circuit is P_1. When capacitor with capacitance C such that $X_L = X_C$ is put in series, the power factor becomes P_2. Calculate $\frac{P_1}{P_2}$. **[*CBSE Delhi 2016*]**

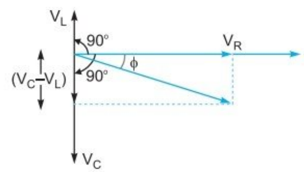
Ans. **Impedance:** The opposition offered by the combination of a resistor and reactive component to the flow of ac is called impedance. Mathematically it is the ratio of rms voltage applied and rms current produced in circuit *i.e.*, $Z = \frac{V}{I}$.

Its unit is ohm (Ω).

Expression for Impedance in *LCR* series circuit: Suppose resistance R, inductance L and capacitance C are connected in series and an alternating source of voltage $V = V_0 \sin \omega t$ is applied across it (fig. a). On account of being in series, the current (i) flowing through all of them is the same.



(a)



(b)

Suppose the voltage across resistance R is V_R voltage across inductance L is V_L and voltage across capacitance C is V_C. The voltage V_R and current i are in the same phase, the voltage V_L will lead the current by angle 90° while the voltage V_C will lag behind the current by angle 90° (fig. *b*). Clearly V_C and V_L are in opposite directions, therefore their resultant potential difference = $V_C - V_L$ (if $V_C > V_L$).

Thus V_R and $(V_C - V_L)$ are mutually perpendicular and the phase difference between them is 90°. As applied voltage across the circuit is V, the resultant of V_R and $(V_C - V_L)$ will also be V. From fig.

$$V^2 = V_R^2 + (V_C - V_L)^2 \quad \Rightarrow \quad V = \sqrt{V_R^2 + (V_C - V_L)^2}$$

But $\quad V_R = R\,i$, $V_C = X_C\, i$ and $V_L = X_L\, i$

where $X_C = \frac{1}{\omega C}$ = capacitance reactance and $X_L = \omega L$ = inductive reactance

$$V = \sqrt{(Ri)^2 + (X_C i - X_L i)^2}$$

Impedance of circuit, $Z = \frac{V}{i} = \sqrt{R^2 + (X_C - X_L)^2}$

i.e.,
$$Z = \sqrt{R^2 + (X_C - X_L)^2} = \sqrt{R^2 + \left(\frac{1}{\omega C} - \omega L\right)^2}$$

Instantaneous current
$$I = \frac{V_0 \sin(\omega t + \phi)}{\sqrt{R^2 + \left(\frac{1}{\omega C} - \omega L\right)^2}}$$

The phase difference (ϕ) between current and voltage is given by, $\tan \phi = \frac{X_C - X_L}{R}$

Resonant Frequency: For resonance $\phi = 0$, so $X_C - X_L = 0$

$$\frac{1}{\omega C} = \omega L \Rightarrow \omega^2 = \frac{1}{LC}$$

$\therefore$ Resonant frequency $\omega_r = \frac{1}{\sqrt{LC}}$

Phase difference (ϕ) in series LCR circuit is given by

$$\tan\phi = \frac{V_C - V_L}{V_R} = \frac{i_m(X_C - X_L)}{i_m R} = \frac{(X_C - X_L)}{R}$$

When current and voltage are in phase

$$\phi = 0 \quad \Rightarrow \quad X_C - X_L = 0 \Rightarrow \quad X_C = X_L$$

This condition is called resonance and the circuit is called resonant circuit.

Case I: $X_L = R$

$\therefore$ $Z = \sqrt{R^2 + X_L^2} = \sqrt{R^2 + R^2} = \sqrt{2}R$

Power factor, $P_1 = \cos\phi = \frac{R}{Z} = \frac{R}{\sqrt{2}R} = \frac{1}{\sqrt{2}}$

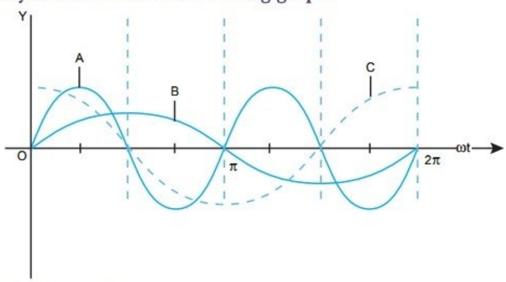
Case II: $X_L = X_C$

$\therefore$ $Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{R^2} = R$

Power factor, $P_2 = \frac{R}{Z} = \frac{R}{R} = 1$

$\therefore$ $\frac{P_1}{P_2} = \mathbf{\frac{1}{\sqrt{2}}}$

Q. 3. A device 'X' is connected to an ac source $V = V_0 \sin \omega t$. The variation of voltage, current and power in one cycle is show in the following graph:



(a) Identify the device 'X'.

(b) Which of the curves, A, B and C represent the voltage, current and the power consumed in the circuit? Justify your answer.

(c) How does its impedance vary with frequency of the *ac* source? Show graphically.

(d) Obtain an expression for the current in the circuit and its phase relation with *ac* voltage.

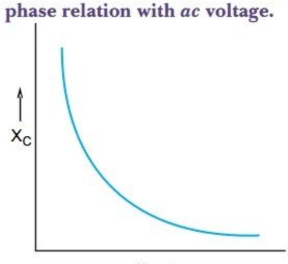
Ans. (a) The device 'X' is a capacitor.

(b) Curve B : Voltage

Curve C : Current

Curve A : Power consumed in the circuit

Reason : This is because current leads the voltage in phase by $\frac{\pi}{2}$ for a capacitor.



(c) Impedance:

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi\nu C}$$

$\Rightarrow \quad X_C \propto \frac{1}{\nu}$

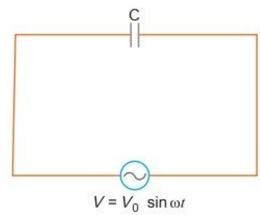
(*d*) Voltage applied to the circuit is

$$V = V_0 \sin \omega t$$

Due to this voltage, a charge will be produced which will charge the plates of the capacitor with positive and negative charges.

$$V = \frac{Q}{C} \qquad \Rightarrow \qquad Q = CV$$

Therefore, the instantaneous value of the current in the circuit is



$$I = \frac{dQ}{dt} = \frac{d(CV)}{dt} = \frac{d}{dt}(CV_0 \sin \omega t)$$

$$\therefore \quad I = \omega C V_0 \cos \omega t = \frac{V_0}{\frac{1}{\omega C}} \sin\left(\omega t + \frac{\pi}{2}\right)$$

$$I = I_0 \sin\left(\omega t + \frac{\pi}{2}\right)$$

where, $I_0 = \frac{V_0}{\frac{1}{\omega C}}$ = Peak value of current

Hence, current leads the voltage in phase by $\frac{\pi}{2}$.

Q. 4. **(*a*) An alternating voltage $V = V_m \sin \omega$ applied to a series *LCR* circuit drives a current given by $i = i_m \sin(\omega t + \phi)$. Deduce an expression for the average power dissipated over a cycle.**

(*b*) For circuits used for transporting electric power, a low power factor implies large power loss in transmission. Explain. **[*CBSE (F) 2011*]**

OR

A voltage $V = V_0 \sin \omega t$ is applied to a series *LCR* circuit. Derive the expression for the average power dissipated over a cycle.

Under what condition is (*i*) no power dissipated even though the current flows through the circuit, (*ii*) maximum power dissipated in the circuit? **[*CBSE (AI) 2014*]**

Ans. (*a*) We have, $V = V_m \sin \omega t$ and $i = i_m \sin(\omega t + \phi)$

and instantaneous power, $P = Vi$

$$= V_m \sin \omega t \,.\, i_m \sin(\omega t + \phi)$$

$$= V_m i_m \sin \omega t \sin(\omega t + \phi)$$

$$= \frac{1}{2} V_m i_m 2 \sin \omega t . \sin(\omega t + \phi)$$

From trigonometric formula

$$2 \sin A \sin B = \cos(A - B) - \cos(A + B)$$

$$\therefore \quad \text{Instantaneous power, } P = \frac{1}{2} V_m i_m [\cos(\omega t - \omega t - \phi) - \cos(\omega t + \phi + \omega t)]$$

$$= \frac{1}{2} V_m i_m [\cos \phi - \cos(2\omega t + \phi)]$$

Average power for complete cycle,

$$\overline{P} = \frac{1}{2} V_m i_m [\cos \phi - \overline{\cos(2\omega t + \phi)}]$$

where $\overline{\cos(\omega t + \phi)}$ is the mean value of $\cos(2\omega t + \phi)$ over complete cycle. But for a complete cycle, $\cos(2\omega t + \phi) = 0$.

$\therefore$ Average power, $\overline{P} = \frac{1}{2} V_m i_m \cos\phi = \frac{V_0}{\sqrt{2}} \frac{i_0}{\sqrt{2}} \cos\phi$

$$\overline{P} = V_{rms} i_{rms} \cos\phi$$

(*i*) If phase angle $\phi = 90°$ (resistance R is not used in the circuit) then no power dissipated.

(*ii*) If phase angle $\phi = 0°$ or circuit is pure resistive (or $X_L = X_C$) at resonance then

Max power, $P = V_{rms} \times I_{rms} = \frac{V_0 I_0}{2}$

(*b*) The power is $P = V_{rms} I_{rms} \cos\phi$. If $\cos\phi$ is small, then current considerably increases when voltage is constant. Power loss, we know is I^2R. Hence, power loss increases.

Q. 5. Find the condition for resonance in a series *LCR* circuit connected to a source $V = V_m \sin \omega t$, where ω can be varied. Give the factors on which the resonant frequency of a series *LCR* circuit depends. Plot a graph showing the variation of electric current with frequency in a series *LCR* circuit. **[*CBSE 2023 (55/1/1)*]**

Ans. Condition for resonance to occur in series *LCR ac* circuit:

For resonance the current produced in the circuit and emf applied must always be in the same phase. Phase difference (ϕ) in series *LCR* circuit is given by

$$\tan\phi = \frac{X_C - X_L}{R}$$

For resonance $\phi = 0 \quad \Rightarrow \quad X_C - X_L = 0$

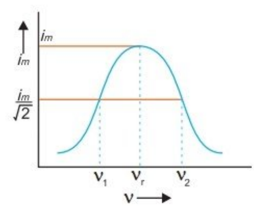
or $\quad X_C = X_L$

If ω_r is resonant frequency, then $X_C = \frac{1}{\omega_r C}$

and $\quad X_C = \omega_r L$

$$\frac{1}{\omega_r C} = \omega_r L \Rightarrow \omega_r = \frac{1}{\sqrt{LC}}$$

Linear resonant frequency, $\nu_r = \frac{\omega_r}{2\pi} = \frac{1}{2\pi\sqrt{LC}}$



Factors on which resonant frequency depends:

(*i*) Inductance, *i.e.*, $\left(\nu_r \propto \frac{1}{\sqrt{L}}\right)$

(*ii*) Capacitance, *i.e.*, $\left(\nu_r \propto \frac{1}{\sqrt{C}}\right)$

The graph of variation of peak current i_m with frequency is shown above in fig. Half power frequencies are the frequencies on either side of resonant frequency for which current reduces to half of its maximum value. In fig., ν_1 and ν_2 are half power frequencies.

Q. 6. Explain with the help of a labelled diagram, the principle and working of an *ac* generator. Write the expression for the emf generated in the coil in terms of speed of rotation. Can the current produced by an *ac* generator be measured with a moving coil galvanometer?

OR

Describe briefly, with the help of a labelled diagram, the basic elements of an *ac* generator. State its underlying principle. Show diagrammatically how an alternating emf is generated by a loop of wire rotating in a magnetic field. Write the expression for the instantaneous value of the emf induced in the rotating loop. **[*CBSE 2023 (55/2/1)*]**

OR

State the working of ac generator with the help of a labelled diagram.

The coil of an *ac* generator having *N* turns, each of area *A*, is rotated with a constant angular velocity ω. Deduce the expression for the alternating emf generated in the coil.

What is the source of energy generation in this device? **[*CBSE (AI) 2011*]**

Ans. **AC generator:** A dynamo or generator is a device which converts mechanical energy into electrical energy.

Principle: It works on the principle of electromagnetic induction. When a coil rotates continuously in a magnetic field, the effective area of the coil linked normally with the magnetic field lines, changes continuously with time. This variation of magnetic flux with time results in the production of an alternating emf in the coil.

Construction: It consists of the four main parts:

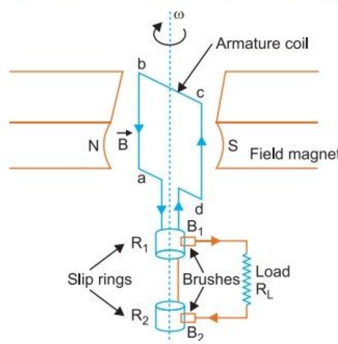
(*i*) **Field Magnet:** It produces the magnetic field. In the case of a low power dynamo, the magnetic field is generated by a permanent magnet, while in the case of large power dynamo, the magnetic field is produced by an electromagnet.

(*ii*) **Armature:** It consists of a large number of turns of insulated wire in the soft iron drum or ring. It can revolve round an axle between the two poles of the field magnet. The drum or ring serves the two purposes: (*a*) It serves as a support to coils and (*b*) It increases the magnetic field due to air core being replaced by an iron core.

(*iii*) **Slip Rings:** The slip rings R_1 and R_2 are the two metal rings to which the ends of armature coil are connected. These rings are fixed to the shaft which rotates the armature coil so that the rings also rotate along with the armature.

(*iv*) **Brushes:** These are two flexible metal plates or carbon rods (B_1 and B_2) which are fixed and constantly touch the revolving rings. The output current in external load R_L is taken through these brushes.

Working: When the armature coil is rotated in the strong magnetic field, the magnetic flux linked with the coil changes and the current is induced in the coil, its direction being given by Fleming's right hand rule. Considering the armature to be in vertical position and as it rotates in clockwise direction, the wire *ab* moves downward and *cd* upward, so that the direction of induced current is shown in fig. In the external circuit, the current flows along $B_1 R_L B_2$. The direction of current remains unchanged during the first half turn of armature. During the second half revolution, the wire *ab* moves upward and *cd* downward, so the direction of current is reversed and in external circuit it flows along $B_2 R_L B_1$. Thus the direction of induced emf and current changes in the external circuit after each half revolution.



Expression for Induced emf: When the coil is rotated with a constant angular speed ω, the angle θ between the magnetic field vector *B* and the area vector *A* of the coil at any instant *t* is $\theta = \omega t$ (assuming $\theta = 0°$ at $t = 0$). As a result, the effective area of the coil exposed to the magnetic field lines changes with time, the flux at any time *t* is

$$\phi_B = BA \cos\theta = BA \cos \omega t$$

From Faraday's law, the induced emf for the rotating coil of N turns is then,

$$\varepsilon = -N\frac{d\phi_B}{dt} = -NBA\frac{d}{dt}(\cos\omega t)$$

Thus, the instantaneous value of the emf is

$$\varepsilon = NBA\ \omega \sin \omega t$$

where $NBA\omega = 2\pi\upsilon NBA$ is the maximum value of the emf, which occurs when $\sin \omega t = \pm 1$. If we denote $NBA\omega$ as ε_0, then

$$\varepsilon = \varepsilon_0 \sin \omega t \quad \Rightarrow \quad \varepsilon = \varepsilon_0 \sin 2\pi\nu t$$

where ν is the frequency of revolution of the generator's coil.

Obviously, the emf produced is alternating and hence the current is also alternating.

Current produced by an *ac* generator cannot be measured by moving coil ammeter; because the average value of *ac* over full cycle is zero.

The source of energy generation is the mechanical energy of rotation of armature coil.

Q. 7. (a) Describe briefly, with the help of a labelled diagram, the working of a step up transformer.

(b) Write any two sources of energy loss in a transformer. **[*CBSE (F) 2012*]**

(c) A step up transformer converts a low voltage into high voltage. Does it not violate the principle of conservation of energy? Explain. **[*CBSE Delhi 2011, 2009*]**

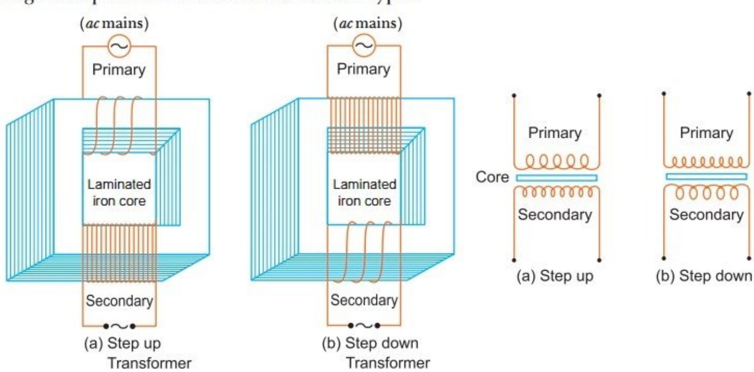
OR

Draw a schematic diagram of a step-up transformer. Explain its working principle. Deduce the expression for the secondary to primary voltage in terms of the number of turns in the two coils. In an ideal transformer, how is this ratio related to the currents in the two coils?

How is the transformer used in large scale transmission and distribution of electrical energy over long distances? **[*CBSE (AI) 2010, (East) 2016*]**

Ans. (*a*) **Transformer:** A transformer converts low voltage into high voltage *ac* and vice-versa.

Construction: It consists of laminated core of soft iron, on which two coils of insulated copper wire are separately wound. These coils are kept insulated from each other and from the iron-core, but are coupled through mutual induction. The number of turns in these coils are different. Out of these coils one coil is called *primary coil* and other is called the *secondary coil*. The terminals of primary coils are connected to *ac* mains and the terminals of the secondary coil are connected to external circuit in which alternating current of desired voltage is required. Transformers are of two types:



1. **Step up Transformer:** It transforms the alternating low voltage to alternating high voltage and in this the number of turns in secondary coil is more than that in primary coil (*i.e.*, $N_S > N_P$).
2. **Step down Transformer:** It transforms the alternating high voltage to alternating low voltage and in this the number of turns in secondary coil is less than that in primary coil (*i.e.*, $N_S < N_P$).

Working Principle: When alternating current source is connected to the ends of primary coil, the current changes continuously in the primary coil; due to which the magnetic flux linked with the secondary coil changes continuously, therefore the alternating emf of same frequency is developed across the secondary.

Let N_P be the number of turns in primary coil, N_S the number of turns in secondary coil and ϕ the magnetic flux linked with each turn. ***We assume that there is no leakage of flux so that the flux linked with each turn of primary coil and secondary coil is the same.*** According to Faraday's laws the emf induced in the primary coil

$$\varepsilon_P = -N_P \frac{\Delta\phi}{\Delta t} \qquad \text{...}(i)$$

and emf induced in the secondary coil

$$\varepsilon_S = -N_S \frac{\Delta\phi}{\Delta t} \qquad \text{...}(ii)$$

From (*i*) and (*ii*)

$$\frac{\varepsilon_S}{\varepsilon_P} = \frac{N_S}{N_P}$$

If the resistance of primary coil is negligible, the emf (ε_P) induced in the primary coil, will be equal to the applied potential difference (V_P) across its ends. Similarly if the secondary circuit is open, then the potential difference V_S across its ends will be equal to the emf (ε_S) induced in it; therefore

$$\frac{V_S}{V_P} = \frac{\varepsilon_S}{\varepsilon_P} = \frac{N_S}{N_P} = r(\text{say})$$

where $r = \frac{N_S}{N_P}$ is called the transformation ratio. If i_P and i_S are the instantaneous currents in primary and secondary coils and there is no loss of energy; then

For about 100% efficiency, Power in primary = Power in secondary

$$V_P\, i_P = V_S\, i_S$$

$$\therefore \quad \frac{i_S}{i_P} = \frac{V_P}{V_S} = \frac{N_P}{N_S} = \frac{1}{r}$$

In step up transformer, $N_S > N_P \;\rightarrow\; r > 1$;

So $\qquad V_S > V_P$ and $i_S < i_P$

i.e., step up transformer increases the voltage, but decreases the current.

In step down transformer, $N_S < N_P \rightarrow \; r < 1$

so $\qquad V_S < V_P$ and $i_S > i_P$

i.e., step down transformer decreases the voltage, but increases the current.

Laminated core: The core of a transformer is laminated to reduce the energy losses due to eddy currents, so that its efficiency may remain nearly 100%.

In a transformer with 100% efficiency (say),

Input power = output power (*i.e.*, $V_P I_P = V_S I_S$)

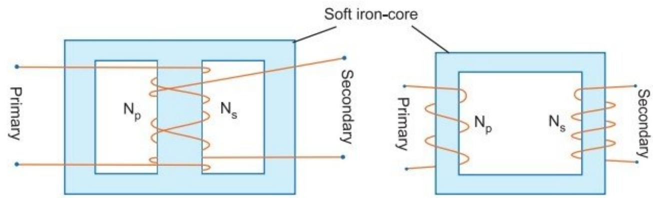
(*b*) The sources of energy loss in a transformer are (*i*) eddy current losses due to iron core (*ii*) flux leakage losses. (*iii*) copper losses due to heating up of copper wires (*iv*) hysteresis losses due to magnetisation and demagnetisation of core.

(*c*) When output voltage increases, the output current automatically decreases to keep the power same. Thus, there is no violation of conservation of energy in a step up transformer.

Q. 8. With the help of a diagram, explain the principle of a device which changes a low voltage into a high voltage but does not violate the law of conservation of energy. Give any one reason why the device may not be 100% efficient. **[*CBSE Sample Paper 2018*]**

Ans. Transformer changes a low voltage into a high voltage without voilating the law of conservation of energy.

Principle: When alternating current source is connected to the ends of primary coil, the current changes continuously in the primary coil; due to which the magnetic flux linked with the secondary coil changes continuously, therefore the alternating emf of same frequency is developed across the secondary.



(a) Two coils on top of each other (b)Two coils on separate limbs of the core

The device may not be 100% efficient due to following energy losses in a transformer:

(*i*) **Joule Heating:** Energy is lost due to heating of primary and secondary windings as heat (I^2Rt).

(*ii*) **Flux Leakage:** Energy is lost due to coupling of primary and secondary coils not being perfect, *i.e.*, whole of magnetic flux generated in primary coil is not linked with the secondary coil.

Q. 9. (*a*) Draw the diagram of a device which is used to decrease high *ac* voltage into a low *ac* voltage and state its working principle. Write four sources of energy loss in this device.

(*b*) A small town with a demand of 1200 kW of electric power at 220 V is situated 20 km away from an electric plant generating power at 440 V. The resistance of the two wire line carrying power is 0.5 Ω per km. The town gets the power from the line through a 4000-220 V step-down transformer at a sub-station in the town. Estimate the line power loss in the form of heat. **[*CBSE 2019 (55/1/2)*]**

Ans. (*a*) Refer to Q. 7, Long Answer Questions

(*b*) Demand of electric power = 1200 kW

Distance of town from power station = 20 km

Two wire = 20 × 2 = 40 km

Total resistance of line = 40 × 0.5 = 20 Ω

The town gets a power of 4000 volts

Power = voltage × current

$$I = \frac{1200 \times 10^3}{4000} = \frac{1200}{4} = 300 \text{ A}$$

The line power loss in the form of heat $= I^2 \times R$

$= (300)^2 \times 20 = 9000 \times 20 =$ **1800 kW**

Q. 10. A 2 μF capacitor, 100 W resistor and 8 H inductor are connected in series with an ac source.

(i) What should be the frequency of the source such that current drawn in the circuit is maximum? What is this frequency called?

(ii) If the peak value of emf of the source is 200 V, find the maximum current.

(iii) Draw a graph showing variation of amplitude of circuit current with changing frequency of applied voltage in a series *LRC* circuit for two different values of resistance R_1 and R_2 ($R_1 > R_2$).

(iv) Define the term 'Sharpness of Resonance'. Under what condition, does a circuit become more selective? **[*CBSE (F) 2016*]**

Ans. (i) For maximum frequency

$$\omega L = \frac{1}{\omega C}$$

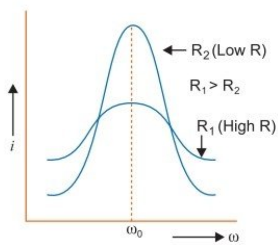
$$\Rightarrow \quad 2\pi\nu \times 8 = \frac{1}{2\pi\nu \times 2 \times 10^{-6}} \Rightarrow (2\pi\nu)^2 = \frac{1}{16 \times 10^{-6}}$$

$$\Rightarrow \quad 2\pi\nu = \frac{1}{4 \times 10^{-3}} \quad \Rightarrow \nu = \frac{250}{2\pi} = \mathbf{39.80\ s^{-1}}$$

This frequency is called resonance frequency.

(ii) Maximum current, $I_0 = \dfrac{E_0}{R} = \dfrac{200}{100} = \mathbf{2\ A}$ [E_0 maximum emf]

(iii)



(iv) $\dfrac{\omega_0}{2\Delta\omega}$ is measure of sharpness of resonance, where ω_0 is the resonant frequency and $2\Delta\omega$ is the bandwidth.

Circuit is more selective if it has greater value of sharpness. The circuit should have smaller bandwidth $\Delta\omega$.

Q. 11. (i) Draw a labelled diagram of *ac* generator. Derive the expression for the instantaneous value of the emf induced in the coil. **[*CBSE Sample Paper 2021*]**

(ii) A circular coil of cross-sectional area 200 cm^2 and 20 turns is rotated about the vertical diameter with angular speed of 50 rad s^{-1} in a uniform magnetic field of magnitude 3.0×10^{-2} T. Calculate the maximum value of the current in the coil. **[*CBSE Delhi 2017*]**

Ans. (i) Refer to Q. 6, Long Answer Questions.

(ii) Given,

$$N = 20,\ A = 200\ \text{cm}^2 = 200 \times 10^{-4}\ \text{m}^2,\ B = 3.0 \times 10^{-2}\ \text{T}$$

$$\omega = 50\ \text{rad s}^{-1}$$

EMF induced in the coil

$$\varepsilon = NBA\omega \sin \omega t$$

Maximum emf induced

$$\varepsilon_{max} = NBA\omega = 20 \times 3.0 \times 10^{-2} \times 200 \times 10^{-4} \times 50 = 600 \text{ mV}$$

Maximum value of current induced

$$I_{max} = \frac{\varepsilon_{max}}{R} = \frac{\mathbf{600}}{\boldsymbol{R}} \textbf{ mA}$$

Q. 12. **(*i*) Draw a labelled diagram of a step-up transformer. Obtain the ratio of secondary to primary voltage in terms of number of turns and currents in the two coils.**

(*ii*) A power transmission line feeds input power at 2200 V to a step-down transformer with its primary windings having 3000 turns. Find the number of turns in the secondary to get the power output at 220 V. **[*CBSE Delhi 2017*]**

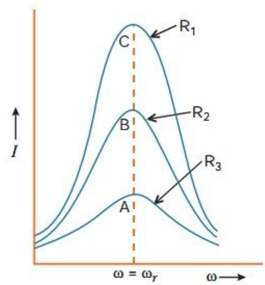
Ans. (*i*) Refer to Q. 7, Long Answer Questions.

(*ii*) Given, $V_P = 2200$ V, $N_P = 3000$ turns, $V_S = 220$ V

We have, $\frac{V_S}{V_P} = \frac{N_S}{N_P}$

$$\Rightarrow \quad N_S = \frac{V_S}{V_P} \times N_P = \frac{220}{2200} \times 3000 = \mathbf{300 \text{ turns}}$$

Q 13. **(*a*) What do you understand by 'sharpness of resonance' for a series *LCR* resonant circuit? How is it related with the quality factor '*Q*' of the circuit? Using the graphs given in the diagram, explain the factors which affect it. For which graph is the resistance (*R*) minimum?**



(*b*) A 2 μF capacitor, 100 Ω resistor and 8 H inductor are connected in series with an *ac* source. Find the frequency of the *ac* source for which the current drawn in the circuit is maximum.

If the peak value of emf of the source is 200 V, calculate the (*i*) maximum current, and (*ii*) inductive and capacitive reactance of the circuit at resonance. **[*CBSE 2019 (55/4/1)*]**

Ans. (*a*) The circuit would be set to have a high Sharpness of Resonance, if the current in the circuit drops rapidly as the frequency of the applied AC source shifts from its resonant value. (Also accept sharpness of resonance = $\omega_0/2\Delta\omega$). ½

Sharpness of Resonance is measured by the quality factor, $Q = \frac{1}{R}\sqrt{\frac{L}{C}}$ ½

Note: Accept the answer if the student write sharpness of resonance = Q – factor. ½

Sharpness of resonance for given value L and C / value of ω, depends on R. R is minimum for circuit C. ½

(*b*) Resonant frequency, $\nu = \frac{1}{2\pi\sqrt{LC}}$ ½

$$= \frac{1}{2 \times 3.14\sqrt{8 \times 2 \times 10^{-6}}}$$

$$= \frac{1000}{8 \times 3.14}$$

$= 39.81$ or 40 Hz (Approximately) ½

(*i*) Here, $V_0 = 200$ V

$$i_0 = \frac{V_0}{Z} = \frac{V_0}{R} \qquad (\because Z = R \text{ at resonance}) \qquad ½$$

$$= \frac{200}{100} = 2 \text{ Ampere}$$

(*ii*) At resonance, ½

$$X_L = X_C$$

Now, $X_L = \omega L = 2\pi\nu L$ ½

$$= 2\pi \times 39.81 \times 8$$

$$= 2000\ \Omega \qquad ½$$

So, $X_C = X_L = 2000\ \Omega$ [*CBSE Marking Scheme 2019 (55/4/1)*]

Questions for Practice

1. Choose and write the correct option in the following questions.

(*i*) The power factor of a series *LCR* circuit at resonance will be [*CBSE 2020 (55/5/1)*]

(*a*) 1 (*b*) 0 (*c*) 1/2 (*d*) $1/\sqrt{2}$

(*ii*) The electric current in a circuit is given by $I = I_0\left(\frac{t}{T}\right)$ for some time. The rms value of current for the period $t = 0$ to $t = T$ is

(*a*) $\frac{I_0}{\sqrt{2}}$ (*b*) $\sqrt{2}I_0$ (*c*) $\frac{I_0}{\sqrt{3}}$ (*d*) $\sqrt{3}I_0$

(*iii*) A 15 Ω resistor, an 80 mH inductor and a capacitor of capacitance *C* are connected in series with a 50 Hz *ac* source. If the source voltage and current in the circuit are in phase, then the value of capacitance is [*CBSE 2022 (55/2/4), Term-1*]

(*a*) 100 μF (*b*) 127 μF (*c*) 142 μF (*d*) 160 μF

(*iv*) A voltage signal is described by :

$$V = V_0 \text{ for } 0 \le t \le \frac{T}{2}$$

$$= 0 \quad \text{for } \frac{T}{2} \le t \le T$$

for a cycle. Its rms value is [*CBSE 2023 (55/3/1)*]

(*a*) $\frac{V_0}{\sqrt{2}}$ (*b*) V_0

(*c*) $\frac{V_0}{2}$ (*d*) $\sqrt{2}\,V_0$

(*v*) An inductor of reactance 1 Ω and a resistor of 2 Ω are connected in series to the terminals of a 6 V (rms) ac source. The power dissipated in the circuit is [*NCERT Exemplar*]

(*a*) 8 W (*b*) 12 W (*c*) 14.4 W (*d*) 18 W

(*vi*) A choke coil is a coil having

(*a*) low inductance and high resistance

(*b*) low inductance and low resistance

(*c*) high inductance and high resistance

(*d*) high inductance and negligible or small resistance (*vii*) The potential differences across the resistance, capacitance and inductance are 80 V, 40 V and 100 V respectively in an *L-C-R* circuit, the power factor for this circuit is

(*a*) 0.4 (*b*) 0.5

(*c*) 0.8 (*d*) 1.0

(*viii*) A 20 volt AC is applied to a circuit consisting of a resistance and a coil with negligible resistance. If the voltage across the resistance is 12 volt, the voltage across the coil is

[*CBSE Sample Paper-2022), Term-1*]

(*a*) 16 V (*b*) 10 V

(*c*) 8 V (*d*) 6 V

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

(a) Both A and R are true and R is the correct explanation of A.

(b) Both A and R are true but R is not the correct explanation of A.

(c) A is true but R is false.

(d) A is false and R is also false.

Assertion (*A*) : The quantity L/R possesses the dimension of time.

Reason (*R*) : In order to reduce the rate of increase of current through a solenoid, we should increase the time constant.

3. An alternating current from a source is given by $i = 10 \sin 314\, t$. What is the effective value of current and frequency of source?

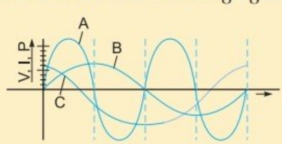
4. Draw a graph to show variation of capacitive-reactance with frequency in an *ac* circuit.

5. (*a*) The peak voltage of an ac supply is 300 V. What is the rms voltage?

(*b*) The rms value of current in an ac circuit is 10 A. What is the peak current? **[*NCERT*]**

6. Mention the two characteristic properties of the material suitable for making core of a transformer. **[*CBSE (AI) 2012*]**

7. A device '*X*' is connected to an ac source $V = V_0 \sin \omega t$. The variation of voltage, current and power in one complete cycle is shown in the following figure.



(*i*) Which curve shows power consumption over a full cycle?

(*ii*) Identify the device '*X*'.

8. How does the resistance differ from impedance? With the help of a suitable phasor diagram, obtain an expression for impedance of a series *LCR* circuit, connected to a source $V = V_m \sin \omega t$.

[*CBSE 2023 (55/1/1)*]

9. A 15.0 μF capacitor is connected to 220 V, 50 Hz source. Find the capacitive reactance and the rms current.

10. How much current is drawn by the primary coil of a transformer which steps down 220 V to 22 V to operate a device with an impedance of 220 Ω?

11. Define power factor. State the conditions under which it is (*i*) maximum and (*ii*) minimum.

[*CBSE Delhi 2010*]

12. When an ac source is connected to an ideal inductor show that the average power supplied by the source over a complete cycle is zero. **[*CBSE (Central) 2016*]**

13. When an *ac* source is connected to an ideal capacitor, show that the average power supplied by the source over a complete cycle is zero. **[*CBSE (North) 2016*]**

14. The current flowing through a pure inductor of inductance 2 mH is $i = 15 \cos 300t$ ampere. What is the (*i*) rms and (*ii*) average value of current for a complete cycle? **[*CBSE (F) 2011*]**

15. In a series *LCR* circuit with an ac source of effective voltage 50 V, frequency $\nu = 50/\pi$ Hz, $R = 300\ \Omega$, $C = 20\ \mu F$ and $L = 1.0$ H. Find the *rms* current in the circuit. **[*CBSE (F) 2014*]**

16. (*a*) A 60 μF capacitor is connected to a 110 V, 60 Hz *ac* supply. Determine the rms value of current in the circuit.
    (*b*) What is the net power absorbed by the circuit in a complete cycle? **[*NCERT*]**

17. A series *LCR* circuit with $R = 20\ \Omega$, $L = 1.5$ H and $C = 35\ \mu F$ is connected to a variable frequency 200 V *ac* supply. When the frequency of the supply equals the natural frequency of the circuit, what is the average power transferred to the circuit in one complete cycle? **[*NCERT*]**

18. You are given three circuit elements *X*, *Y* and *Z*. When the element *X* is connected across an *ac* source of a given voltage, the current and the voltage are in the same phase. When the element *Y* is connected in series with *X* across the source, voltage is ahead of the current in phase by $\pi/4$. But the current is ahead of the voltage in phase by $\pi/4$ when *Z* is connected in series with *X* across the source. Identify the circuit elements *X*, *Y* and *Z*.

    When all the three elements are connected in series across the same source, determine the impedance of the circuit.

    Draw a plot of the current versus the frequency of applied source and mention the significance of this plot.

19. A resistor *R* and an inductor *L* are connected in series to a source $V = V_0 \sin \omega t$. Find the
    (*a*) peak value of the voltage drops across *R* and across *L*,
    (*b*) phase difference between the applied voltage and current. Which of them is ahead?
    [*CBSE 2020 (55/1/2)*]

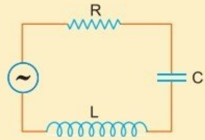
20. An ac source $V = V_m \sin \omega t$ connected across an ideal capacitor. Derive the expression for the (*i*) current flowing in the circuit, and (*ii*) rectance of the capacitor. Plot a graph of current *i* versus ωt.
    [*CBSE 2023 (55/3/1)*]

21. A series combination of an inductor *L*, a capacitor *C* and a resistor *R* is connected across an *ac* source of voltage in a circuit. Obtain an expression for the average power consumed by the circuit. Find power factor for (*i*) purely inductive circuit, and (*ii*) purely resistive circuit.
    [*CBSE 2023 (55/3/1)*]

22. A resistor of 100 Ω and a capacitor of $100/\pi\ \mu F$ are connected in series to a 220 V, 50 Hz ac supply.
    (*a*) Calculate the current in the circuit.
    (*b*) Calculate the (rms) voltage across the resistor and the capacitor. Do you find the algebraic sum of these voltages more than the source voltage? If yes, how do you resolve the paradox?
    [*CBSE Chennai 2015*]

23. A 100 Ω resistor is connected to a 220 V, 50 Hz ac supply:
    (*a*) What is the rms value of current in the circuit?
    (*b*) What is the net power consumed over a full cycle? **[*NCERT*]**

24. The figure shows a series LCR circuit with L = 5.0 H, C = 80 μF, R = 40 Ω connected to a variable frequency 240 V source. Calculate.



(*i*) The angular frequency of the source which drives the circuit at resonance.

(*ii*) The current at the resonating frequency.

(*iii*) The rms potential drop across the capacitor at resonance. **[*CBSE Delhi 2012*]**

25. (*a*) For a given *ac*, $i = i_m \sin \omega t$, show that the average power dissipated in a resistor R over a complete cycle is $\frac{1}{2} i_m^2 R$.

(*b*) A light bulb is rated at 100 W for a 220 V *ac* supply. Calculate the resistance of the bulb. **[*CBSE (AI) 2013*]**

26. Determine the current and quality factor at resonance for a series LCR circuit with L = 1.00 mH, C = 1.00 nF and R = 100 Ω connected to an *ac* source having peak voltage of 100 V. **[*CBSE (F) 2011*]**

27. A circuit is set up by connecting inductance L = 100 mH, resistor R = 100 Ω and a capacitor of reactance 200 Ω in series. An alternating emf of $150\sqrt{2}$ V, 500/π Hz is applied across this series combination. Calculate the power dissipated in the resistor. **[*CBSE (F) 2014*]**

28. (*a*) State the condition for resonance to occur in series LCR *ac* circuit and derive an expression for resonant frequency. **[*CBSE Delhi 2010*]**

(*b*) Draw a plot showing the variation of the peak current (i_m) with frequency of the *ac* source used. Define the quality factor Q of the circuit.

29. (*a*) Derive the expression for the current flowing in an ideal capacitor and its reactance when connected to an *ac* source of voltage $V = V_0 \sin \omega t$.

(*b*) Draw its phasor diagram.

(*c*) If resistance is added in series to capacitor, what changes will occur in the current flowing in the circuit and phase angle between voltage and current? **[*CBSE Sample Paper 2021*]**

30. A circuit containing a 80 mH inductor and a 60 μF capacitor in series is connected to a 230 V, 50 Hz supply. The resistance of the circuit is negligible.

(*a*) Obtain the current amplitude and rms values.

(*b*) Obtain the rms values of potential drops across each element. **[*NCERT*]**

Answers

1. (*i*) (*a*) (*ii*) (*c*) (*iii*) (*b*) (*iv*) (*a*) (*v*) (*c*) (*vi*) (*d*) (*vii*) (*c*) (*viii*) (*a*)

2. (*b*) **3.** 50 Hz **9.** 212.31 Ω, 1.03 A **10.** 0.1 A, 0.01 A **14.** (*i*) $7.5\sqrt{2}$ A (*ii*) 0

15. 0.1 A **16.** (*a*) 2.49 A (*b*) 0 **17.** 2 kW

21. (*a*) 1.56 A (*b*)156 V , 156 V

23. (*a*) 2.2 A (*b*) 484 W **24.** (*i*) 50 rads^{-1} (*ii*) 6 A (*iii*) 1500 V **25.** 484 Ω

26. 0.707 A, 10 **27.** 225 W **30.** (*a*) 11.6 A, 8.23 A (*b*) 207 V, 237 V

8 Electromagnetic Waves

POINTS TO REMEMBER

1. Need for Displacement Current

Ampere's circuital law for conduction current during charging of a capacitor was found inconsistent. Therefore, Maxwell modified Ampere's circuital law by introducing displacement current. It is given by $I_d = \varepsilon_0 \frac{d\phi_E}{dt}$

Modified Ampere's circuital law is:

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 \left(I + \varepsilon_0 \frac{d\phi_E}{dt} \right)$$

where ϕ_E = electric flux.

2. Electromagnetic Waves

The waves propagating in space through electric and magnetic fields varying in space and time simultaneously are called electromagnetic waves.

The electromagnetic waves are produced by an accelerated or decelerated charge or LC circuit. The frequency of EM waves is

$$\nu = \frac{1}{2\pi\sqrt{LC}}$$

3. Characteristics of Electromagnetic Waves

(*i*) The electromagnetic waves travel in free-space with the speed of light ($c = 3 \times 10^8$ m/s) irrespective of their wavelength.

(*ii*) Electromagnetic waves are neutral, so they are not deflected by electric and magnetic fields.

(*iii*) The electromagnetic waves show properties of reflection, refraction, interference, diffraction and polarisation.

(*iv*) In electromagnetic wave the electric and magnetic fields are always in the same phase.

(*v*) The ratio of magnitudes of electric and magnetic field vectors in free space is constant equal to c.

$$\frac{E}{B} = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = c = 3 \times 10^8 \text{ m/s}$$

(*vi*) The speed of electromagnetic waves in a material medium is given by

$$v = \frac{1}{\sqrt{\mu\,\varepsilon}} = \frac{c}{\sqrt{\mu_r \varepsilon_r}} = \frac{c}{n},$$ where n is the refractive index.

[Note : We also use μ for refractive index] (*vii*) In an electromagnetic wave the energy is propagated by means of electric and magnetic field vectors in the direction of propagation of wave.

(*viii*) In electromagnetic wave the average values of electric energy density and magnetic energy density are equal

$$\left(\frac{1}{2}\varepsilon_0 E^2\right)_{av} = \left(\frac{B^2}{2\mu_0}\right)_{av}$$

(*ix*) The electric vector of electromagnetic wave is responsible for optical effects and is also called the light vector.

(*x*) Electromagnetic waves carry energy and momentun $E = \frac{hc}{\lambda}, p = \frac{U}{c} = mc$

4. Transverse Nature of Electromagnetic Waves

The electromagnetic waves are transverse in nature. In electromagnetic waves the electric and magnetic fields are mutually perpendicular and also perpendicular to the direction of wave propagation, such that $\vec{E}$, $\vec{B}$ and $\vec{K}$ form a right handed set ($\vec{K}$ is propagation vector along the direction of propagation).

5. Electromagnetic Spectrum

The electromagnetic waves have a continuous wavelength starting from short gamma rays to long radiowaves. The orderly distribution of wavelength of EM waves is called the electromagnetic spectrum. The complete spectrum is given in the following table:

S. No.	Name	Wavelength Range (m)	Frequency Range (Hz)
(i)	Gamma rays	$10^{-13} - 10^{-10}$	$3 \times 10^{23} - 3 \times 10^{18}$
(ii)	X-rays	$10^{-10} - 10^{-8}$	$3 \times 10^{18} - 3 \times 10^{16}$
(iii)	Ultraviolet rays	$10^{-8} - 4\times10^{-7}$	$3 \times 10^{16} - 7.5 \times 10^{14}$
(iv)	Visible light	$4 \times 10^{-7} - 7.5 \times 10^{-7}$	$7.5 \times 10^{14} - 4 \times 10^{14}$
(v)	Infra red light	$7.5 \times 10^{-7} - 10^{-3}$	$4 \times 10^{14} - 3 \times 10^{12}$
(vi)	Microwaves	$10^{-3} - 10^{-1}$	$3 \times 10^{12} - 10^{9}$
(vii)	Radio waves	$10^{-1} - 10^{4}$	$10^{9} - 3 \times 10^{4}$

6. Wavelength Range of Visible Spectrum

Visible light has a continuous wavelength starting from 400 nm to 750 nm; for convenience it is divided into 7 colours.

V	Violet	400 nm — 420 nm
I	Indigo	420 nm — 450 nm
B	Blue	450 nm — 500 nm
G	Green	500 nm — 570 nm
Y	Yellow	570 nm — 600 nm
O	Orange	600 nm — 650 nm
R	Red	650 nm — 750 nm

7. Uses of Electromagnetic Spectrum

(*i*) **γ-rays** are highly penetrating, they can penetrate thick iron blocks. Due to high energy, they are used to initiate some nuclear reactions. γ-rays are produced in nuclear reactions. In medicine, they are used to destroy cancer cells.

(*ii*) **X-rays** are used in medical diagnostics to detect fractures in bones, tuberculosis of lungs, presence of stone in gallbladder and kidney. They are used in engineering to check flaws in bridges. In physics X-rays are used to study crystal structure.

(*iii*) **Ultraviolet rays** provide vitamin *D*. These are harmful for skin and eyes. They are used to sterilise drinking water and surgical instruments. They are used to detect invisible writing, forged documents, finger prints in forensic lab and to preserve food items.

(*iv*) **Infrared rays** are produced by hot bodies and molecules. These waves are used for long distance photography and for therapeutic purposes.

(*v*) **Microwaves** are produced by special vacuum tubes, namely; klystrons, magnetrons and gunn diodes. Their frequency range is 3 GHz to 300 GHz.

They are used in RADAR systems for aircraft navigation and microwave used in homes.

(*vi*) **Radiowaves** are used for broadcasting programmes to distant places. According to frequency range, they are divided into following groups

(*a*) Medium frequency band or medium waves 0.3 to 3 MHz

(*b*) Short waves or short frequency band 3 MHz — 30 MHz

(*c*) Very high frequency (VHF) band 30 MHz to 300 MHz

(*d*) Ultrahigh frequency (UHF) band 300 MHz to 3000 MHz

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Multiple Choice Questions

Choose and write the correct option(s) in the following questions.

1. One requires 11 eV of energy to dissociate a carbon monoxide molecule into carbon and oxygen atoms. The minimum frequency of the appropriate electromagnetic radiation to achieve the dissociation lies in [*NCERT Exemplar*]

(*a*) visible region (*b*) infrared region

(*c*) ultraviolet region (*d*) microwave region

2. A plane electromagnetic wave travelling along X-axis has a wavelength 10.0 mm. The electric field points along Y-direction and has peak value of 30 V/m. Then the magnetic field in terms of x in metre and t in second may be expressed as

(*a*) $30 \sin 200\pi\,(ct - x)$ (*b*) $10^{-7} \sin 200\pi\,(ct - x)$

(*c*) $30 \sin \frac{2\pi}{10}(ct - x)$ (*d*) $10^{-7} \sin \frac{2\pi}{10}(ct - x)$

3. In the process of charging of a capacitor, the current produced between the plates of the capacitor is (where symbols have their usual meanings) [*CBSE 2023 (55/1/1)*]

(*a*) $\mu_0 \frac{d\phi_E}{dt}$ (*b*) $\frac{1}{\mu_0}\frac{d\phi_E}{dt}$

(*c*) $\varepsilon_0 \frac{d\phi_E}{dt}$ (*d*) $\frac{1}{\varepsilon_0}\frac{d\phi_E}{dt}$

4. A linearly polarised electromagnetic wave given as $E = E_0\hat{i}\cos(kz - \omega t)$ is incident normally on a perfectly reflecting infinite wall at $z = a$. Assuming that the material of the wall is optically inactive, the reflected wave will be given as [*NCERT Exemplar*]

(*a*) $E_r = -E_0\hat{i}\cos(kz - \omega t)$ (*b*) $E_r = E_0\hat{i}\cos(kz + \omega t)$

(*c*) $E_r = -E_0\hat{i}\cos(kz + \omega t)$ (*d*) $E_r = E_0\hat{i}\sin(kz - \omega t)$

16. An electromagnetic wave of frequency 3.0 MHz passes from vacuum into a dielectric medium with relative permittivity $\varepsilon_r = 4.0$. Then

(a) wavelength is doubled and frequency remains unchanged
(b) wavelength is doubled and frequency becomes half
(c) wavelength is halved and frequency remains unchanged
(d) wavelength and frequency both remains unchanged

17. An electromagnetic wave radiates outwards from a dipole antenna, with E_0 as the amplitude of its electric field vector. The electric field E_0 which transports significant energy from the source falls off as [*NCERT Exemplar*]

(a) $\frac{1}{r^3}$ (b) $\frac{1}{r^2}$ (c) $\frac{1}{r}$ (d) remains constant

18. A plane electromagnetic wave of energy U is reflected from the surface. Then the momentum transferred by electromagnetic wave to the surface is

(a) 0 (b) $\frac{U}{c}$ (c) $\frac{2U}{c}$ (d) $\frac{U}{2c}$

19. The rms value of the electric field of light coming from the sun is 720 N/C. The average total energy density of the electromagnetic wave is

(a) 4.58×10^{-6} J/m^3 (b) 6.37×10^{-9} J/m^3
(c) 1.35×10^{-12} J/m^3 (d) 3.3×10^{-3} J/m^3

20. A plane electromagnetic wave propagating along x direction can have the following pairs of E and B [*NCERT Exemplar*]

(a) E_x, B_y (b) E_y, B_z (c) B_x, E_y (d) E_z, B_y

21. Electromagnetic waves used as a diagnostic tool in medicine are [*CBSE 2020 (55/2/1)*]

(a) X-rays (b) ultraviolet rays
(c) infrared radiation (d) ultrasonic waves

22. A welder wears special glasses to protect his eyes mostly from the harmful effect of [*CBSE 2020 (55/2/2)*]

(a) very intense visible light (b) infrared radiation
(c) ultraviolet rays (d) microwaves

23. Displacement current exists only when [*CBSE 2020 (55/2/1)*]

(a) electric field is changing. (b) magnetic field is changing.
(c) electric field is not changing. (d) magnetic field is not changing.

24. During the propagation of electromagnetic waves in a medium

(a) electric energy density is double of the magnetic energy density.
(b) electric energy density is half of the magnetic energy density.
(c) electric energy density is equal to the magnetic energy density.
(d) both electric and magnetic energy densities are zero.

Answers

1. (c)	**2.** (b)	**3.** (c)	**4.** (b)	**5.** (b)	**6.** (a)
7. (d)	**8.** (d)	**9.** (b)	**10.** (c)	**11.** (c)	**12.** (a), (b), (c)
13. (c)	**14.** (a)	**15.** (b)	**16.** (c)	**17.** (c)	**18.** (c)
19. (a)	**20.** (b), (d)	**21.** (a)	**22.** (c)	**23.** (a)	**24.** (c)

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(*a*) *Both A and R are true and R is the correct explanation of A.*

(*b*) *Both A and R are true but R is not the correct explanation of A.*

(*c*) *A is true but R is false.*

(*d*) *A is false and R is also false.*

1. **Assertion** (*A*) : Short wave band is used for transmission of radiowaves to large distances.
   Reason (*R*) : Short waves are reflected by earth's ionosphere.
2. **Assertion** (*A*) : Light can travel in vacuum but sound cannot.
   Reason (*R*) : Light is an electromagnetic wave but sound is a mechanical wave.
3. **Assertion** (*A*) : If earth's atmosphere disappears the average surface temperature will increase.
   Reason (*R*) : Without an atmosphere to trap Earth's heat, the temperature will increase.
4. **Assertion** (*A*) : Gamma rays are more energetic than X-rays.
   Reason (*R*) : Gamma rays are of nuclear origin while X-rays originate from heavy atoms.
5. **Assertion** (*A*) : The speed of electromagnetic waves in free space is maximum for gamma rays and minimum for radiowaves.
   Reason (*R*) : For waves with same wavelengths this just means that the speed will be equal to c.
6. **Assertion** (*A*) : In an electromagnetic wave, electric field vector and magnetic field vector are mutually perpendicular.
   Reason (*R*) : Electromagnetic waves are transverse.
7. **Assertion** (*A*) : Electromagnetic wave is produced by accelerated charge.
   Reason (*R*) : An accelerated charge produces both electric and magnetic fields and also radiates them.
8. **Assertion** (*A*) : Microwaves are better carriers of signals than optical waves.
   Reason (*R*) : Microwaves move faster than optical waves.
9. **Assertion** (*A*) : UV radiation causes photo dissociation of ozone into O_2 and O, thus causing damage to the stratospheric ozone layer.
   Reason (*R*) : Ozone hole is resulting in global warming and climate change. [*AIIMS 2015*]
10. **Assertion** (*A*) : When a charged particle moves in a circular path, it produces electromagnetic wave.
    Reason (*R*) : Charged particle has acceleration. [*AIIMS 2016*]

Answers

1. (*a*) **2.** (*a*) **3.** (*d*) **4.** (*a*) **5.** (*d*) **6.** (*b*) **7.** (*a*)
8. (*c*) **9.** (*b*) **10.** (*a*)

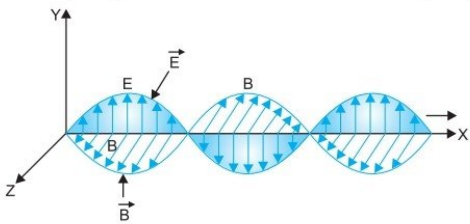
Case-based/Passage-based Questions

Read the paragraph given below and answer the questions that follow:

Electromagnetic Wave: Maxwell, in 1865, pointed out that when either an electric or a magnetic field is changing with time, a field of the other kind is induced in adjacent regions of space. From this Maxwell concluded that variation of electric and magnetic field vectors perpendicular to each other leads to the production of electromagnetic disturbances which show properties of waves and can travel in space even without any material medium. These waves are called electromagnetic waves.

Electromagnetic waves with macroscopic wavelengths were first produced in the laboratory in 1887 by the German physicist Heinrich Hertz. Seven years after Hertz, Jagdish Chandra Bose, working at Calcutta (now Kolkata) succeeded in producing and observing electromagnetic waves of much shorter wavelength (25 mm to 5 mm). At around the same time, Guglielmo Marconi in Italy followed Hertz's work and succeeded in transmitting electromagnetic waves over distances of many kilometers.

Electromagnetic waves have a broad frequency range 10^3 Hz to 10^{22} Hz. They can travel with speed of light (c) in vacuum. They obey the relation $c = \nu\lambda$, where ν is frequency and λ is wavelength.



(*i*) Which of the following electromagnetic wave in order of increasing frequency.

(*a*) Microwave < Infrared < Ultraviolet < γ-rays

(*b*) γ-rays < Ultraviolet < Infrared < Microwave

(*c*) Ultraviolet < Infrared < Microwave < γ-rays

(*d*) γ-rays < Microwave < Infrared < Ultraviolet

(*ii*) Light wave constitutes

(*a*) electromagnetic waves (*b*) longitudinal waves

(*c*) mechanical waves (*d*) magnetic waves

(*iii*) If we want to produce electromagnetic waves of wavelength 500 km by an oscillating charge; then frequency of oscillating charge must be

(*a*) 600 Hz (*b*) 500 Hz (*c*) 167 Hz (*d*) 15 Hz

(*iv*) The angle between $\vec{E}$ and $\vec{B}$ in an electromagnetic wave is

(*a*) 180° (*b*) 120° (*c*) 90° (*d*) 45°

OR

The electric field associated with an EM wave in vacuum is given by $\vec{E} = 40\cos(KZ - 6\times10^8\, t)\hat{i}$, where E, Z and t are in volt/m, metre and second respectively. The value of vector K is

(*a*) 2 m^{-1} (*b*) 0·5 m^{-1} (*c*) 6 m^{-1} (*d*) 3 m^{-1}

Explanations

(i) (a) Microwave < Infrared < Ultraviolet < γ-rays

(ii) (a) electromagnetic waves

(iii) (a) $\nu = \frac{c}{\lambda} = \frac{3\times10^8}{500\times10^3} = 600$ Hz

(iv) (c) For EM wave $\vec{B}$ & $\vec{E}$ are mutually perpendicular to each other and to the axis of propagation.

OR

(a) Propagation constant,

$$K = \frac{\omega}{c} = \frac{6\times10^8}{3\times10^8} = 2\ \text{m}^{-1}$$

CONCEPTUAL QUESTIONS

Q. 1. How is the speed of EM-waves in vacuum determined by the electric and magnetic fields? *[CBSE Delhi 2017]*

Ans. Speed of EM waves is determined by the ratio of the peak values of electric field vector and magnetic field vector.

$$c = \frac{E_0}{B_0}$$

Q. 2. Illustrate by giving suitable examples, how you can show that electromagnetic waves carry both energy and momentum. *[CBSE 2019 (55/4/1)]*

Ans. When EM waves falls on charged particles, they set the charges into motion. This illustrates that the EM waves have energy and momentum. 1

Alternatively

When the sun shines on your hand, you feel energy being absorbed from the EM waves.

Alternatively

The radio & TV signals carry energy from one place to another (Give full marks if student explains on the basis of any one of above example)

Example – Photo-electric effect

[CBSE Marking Scheme 2019 (55/4/1)]

Q. 3. In which situation is there a displacement current but no conduction current? *[CBSE South 2016]*

Ans. During charging or discharging there is a displacement current but no conduction current between plates of capacitor.

Q. 4. The charging current for a capacitor is 0.25 A. What is the displacement current across its plates? *[CBSE (F) 2016]*

Ans. The displacement current is equal to the charging current. So, displacement current is also 0.25 A.

Q. 5. In which directions do the electric and magnetic field vectors oscillate in an electromagnetic wave propagating along the *x*-axis? **[*CBSE (AI) 2017*]**

Ans.

Electric and magnetic field vectors are perpendicular to the direction of propogation of the wave.
The electric field vector is along positive Y-axis and the magnetic field is oscillating along the positive z axis. So that $(E\hat{j} \times B\hat{k}) = EB\hat{i}$.
The wave is propogating along the +ve x axis.

[*Topper's Answer 2017*]

Q. 6. How is displacement current produced between the plates of a parallel plate capacitor during charging? **[*CBSE 2020 (55/1/2)*]**

Ans. With the change in charge on the capacitor plates electric field/electric flux changes. Hence displacement current is produced./ $I_d = \varepsilon_0 \dfrac{d\phi_E}{dt}$ **1**

[*CBSE Marking Scheme 2020 (55/1/2)*]

Q. 7. Differentiate between conduction current and displacement current. **[*CBSE 2020 (55/1/3)*]**

Ans. Conduction current is due to the flow of charges whereas the displacement current due to the change of electric field/ flux between the capacitor plates or due to changing electric field/ flux. **1**

[*CBSE Marking Scheme 2020 (55/1/3)*]

Q. 8. Why are infra-red radiations referred to as heat waves? Name the radiations which are next to these radiations in the electromagnetic spectrum having (*i*) shorter wavelength (*ii*) longer wavelength. **[*CBSE (F) 2013*]**

Ans. Infrared waves are produced by hot bodies and molecules, so are referred to as heat waves.

(*i*) Electromagnetic wave having short wavelength than infrared waves are visible, UV, X-rays and γ-rays.

(*ii*) Electromagnetic wave having longer wavelength than infrared waves are microwaves, radio waves.

Q. 9. The amplitude of the magnetic field of a harmonic electromagnetic wave in vacuum is B_0 = 510 nT. What is the amplitude of the electric field part of the wave? **[*NCERT*]**

Ans. The relation between magnitudes of magnetic and electric field vectors in vacuum is

$$\frac{E_0}{B_0} = c \quad \Rightarrow \quad E_0 = B_0 c$$

Here, $B_0 = 510\,\text{nT} = 510 \times 10^{-9}\,\text{T}, c = 3 \times 10^8\,\text{ms}^{-1}$

$$E_0 = 510 \times 10^{-9} \times 3 \times 10^8 = \mathbf{153\,N/C.}$$

Q. 10. Name the electromagnetic radiations used for (*a*) water purification, and (*b*) eye surgery. **[*CBSE 2018*]**

Ans. (*a*) Ultraviolet rays

(*b*) Ultraviolet rays/laser

Q. 11. How are electromagnetic waves produced by accelerating charges? *[CBSE 2019 (55/2/1)]*

Ans. Accelerated charge produces an oscillating electric field which produces an oscillating magnetic filed, which is a source of oscillating electric field, and so on. Thus electromagnetic waves are produced. **1**

[CBSE Marking Scheme 2019 (55/2/1)]

Q. 12. Why is the orientation of the portable radio with respect to broadcasting station important? *[NCERT Exemplar] [HOTS]*

Ans. As electromagnetic waves are plane polarised, so the receiving antenna should be parallel to electric/magnetic part of the wave.

Q. 13. The charge on a parallel plate capacitor varies as $q = q_0 \cos 2\pi\nu t$. The plates are very large and close together (area = A, separation = d). Neglecting the edge effects, find the displacement current through the capacitor? *[NCERT Exemplar] [HOTS]*

Ans. Conduction current I_C = Displacement current I_D

$$I_C = I_D = \frac{dq}{dt} = \frac{d}{dt}(q_0 \cos 2\pi\nu t) = -2\pi q_0 \nu \sin 2\pi\nu t$$

Q. 14. A variable frequency ac source is connected to a capacitor. How will the displacement current change with decrease in frequency? *[NCERT Exemplar] [HOTS]*

Ans. On decreasing the frequency, reactance $X_C = \dfrac{1}{\omega C}$ will increase which will lead to decrease in conduction current. In this case $I_D = I_C$, hence displacement current will decrease.

Q. 15. Professor C.V. Raman surprised his students by suspending freely a tiny light ball in a transparent vacuum chamber by shining a laser beam on it. Which property of em waves was he exhibiting? Give one more example of this property. *[NCERT Exemplar] [HOTS]*

Ans. Electromagnetic waves exert radiation pressure. Tails of comets are due to solar radiation.

CONSTRUCTED RESPONSE QUESTIONS AS PER NEP

Very Short Answer Questions

Each of the following questions are of 2 marks.

Q. 1. Consider an induced magnetic field due to changing electric field and an induced electric field due to changing magnetic field. Which one is more easily observed? Justify your answer. *[CBSE 2023 (55/1/1)]*

Ans. Electric field which is easily observed because an *a.c.* circuit displacement current can be increased by increasing the angular frequency of current. The electric field increase due to changing magnetic field can be increased by taking more no. of turns of the coil. But magnetic field set up due to this displacement current is very small so it can easily observed.

Q. 2. Suppose that the electric field amplitude of an electromagnetic wave is $E_0 = 120$ N/C and that its frequency $\nu = 50.0$ MHz. (*a*) Determine B_0, ω, k and λ (*b*) Find expressions for $\vec{E}$ and $\vec{B}$. *[NCERT]*

Ans. (*a*) We have $\dfrac{E_0}{B_0} = c \;\Rightarrow\; B_0 = \dfrac{E_0}{c} = \dfrac{120}{3 \times 10^8} = \mathbf{4 \times 10^{-7}\,T}$

$$\omega = 2\pi\nu = 2 \times 3.14 \times 50 \times 10^6 = \mathbf{3.14 \times 10^8\ rad s^{-1}}$$

$$k = \frac{\omega}{c} = \frac{3.14 \times 10^8}{3 \times 10^8} = \mathbf{1.05\ rad\,m^{-1}}$$

Wavelength, $\lambda = \frac{c}{\nu} = \frac{3 \times 10^8}{50.0 \times 10^6} = \mathbf{6.00\ m.}$

(*b*) If wave is propagating along X-axis, electric field will be along Y-axis and magnetic field along Z-axis.

$$\vec{E} = E_0 \sin(kx - \omega t)\hat{j} \text{ where } x \text{ is in m and } t \text{ in s}$$

$$\Rightarrow \quad \vec{E} = \mathbf{120 \sin(1.05\,x - 3.14 \times 10^8 t)\,\hat{j}\ N/C}$$

$$\vec{B} = B_0 \sin(kx - \omega t)\hat{k}$$

$$= \mathbf{(4 \times 10^{-7}) \sin(1.05\,x - 3.14 \times 10^8 t)\hat{k}\ tesla.}$$

Q. 3. Write the generalised expression for the Ampere's circuital law in terms of the conduction current and the displacement current. Mention the situation when there is:

(*i*) only conduction current and no displacement current.

(*ii*) only displacement current and no conduction current. ***[CBSE (F) 2013]***

Ans. Generalised Ampere's circuital Law—

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 I_C + \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$$

Line integral of magnetic field over closed loop is equal to μ_0 times sum of conduction current and displacement current.

(*i*) In case of steady electric field in a conducting wire, electric field does not change with time, conduction current exists in the wire but displacement current may be zero. So, $\oint \vec{B} . \vec{dl} = \mu_0 I_C$.

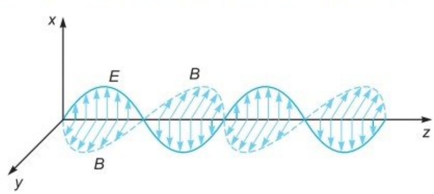
(*ii*) In large region of space, where there is no conduction current, but there is only a displacement current due to time varying electric field (or flux). So, $\oint \vec{B} . \vec{dl} = \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$.

Q. 4. (*a*) How does oscillating charge produce electromagnetic waves?

(*b*) Sketch a schematic diagram depicting oscillating electric and magnetic fields of an em wave propagating along + *z*-direction. ***[CBSE (F) 2014, Delhi 2016]***

Ans. (*a*) An oscillating charge produces an oscillating electric field in space, which produces an oscillating magnetic field. The oscillating electric and magnetic fields regenerate each other, and this results in the production of em waves in space.

(*b*) Electric field is along *x*-axis and magnetic field is along *y*-axis.

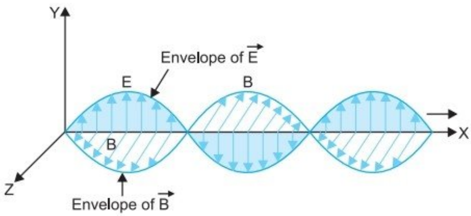


Q. 5. (a) An EM wave is travelling in a medium with a velocity $\vec{v} = v\hat{i}$. Draw a sketch showing the propagation of the EM wave, indicating the direction of the oscillating electric and magnetic fields.

(b) How are the magnitudes of the electric and magnetic fields related to the velocity of the EM wave? ***[CBSE Delhi 2013]***

Ans. The direction of propagation of electromagnetic wave is given by $\vec{E} \times \vec{B}$

(a) $\hat{i} = \hat{j} \times \hat{k}$.



(b) The speed of electromagnetic wave $|c| = \dfrac{|E_0|}{|B_0|}$

Q. 6. Which of the following electromagnetic waves has (a) minimum wavelength, and (b) minimum frequency? Write one use of each of these two waves.

Infrared waves, Microwaves, γ-rays and X-rays ***[CBSE 2020 (55/2/1)]***

Ans.

The electromagnetic wave having :-
(a) minimum wavelength is — γ-rays. ½
(b) minimum frequency is — Microwaves ½

Use:- (a) γ-rays:- γ-ray is used to treat cancer ½
(b) Microwaves:- It is used to heat food in microwave ovens. ½

[Topper's Answer 2020]

Q. 7. (i) How are infrared waves produced? Write their one important use.

(ii) The thin ozone layer on top of the stratosphere is crucial for human survival. Why? ***[CBSE East 2016; 2019 (55/4/1)]***

Ans. (i) Infrared waves are produced by hot bodies and molecules.
Important use:

(a) To treat muscular strains (b) To reveal the secret writings on the ancient walls (c) For producing dehydrated fruits (d) Solar heater (e) Solar cooker (*Any one*)

(ii) Ozone layer protects us from harmful UV rays.

Q. 8. (i) Which segment of electromagnetic waves has highest frequency? How are these waves produced? Give one use of these waves.

(ii) Which EM waves lie near the high frequency end of visible part of EM spectrum? Give its one use. In what way this component of light has harmful effects on humans? ***[CBSE (F) 2016]***

Ans. (i) Gamma rays have the highest frequency. These are produced during nuclear reactions and also emitted by radioactive nuclei. They are used in medicine to destroy cancer cells.

(ii) Ultraviolet rays lie near the high frequency end of visible part of EM spectrum. They are used to sterlise drinking water and surgical instruments. Exposure to UV radiation induces the production of more melanin, causing tanning of the skin.

Q. 9. How does an oscillating charge radiate an electromagnetic wave? Give the relation between the frequency of radiated wave and the frequency of oscillating charge. [*CBSE 2020 (55/3/1)*]

Ans. An oscillating charge produces an oscillating electric field in space, which produces an oscillating magnetic field, which in turn, is a source of oscillating electric field, and so on. The oscillating electric and magnetic fields thus regenerate each other, as the wave propagates through the space. **1**

The frequency of the electromagnetic wave equals the frequency of oscillation of the charge. **1**

[***CBSE Marking Scheme 2020 (55/3/1)***]

Q. 10. How are infrared waves produced? Why are these waves referred to as heat waves? Give any two uses of infrared waves. [*CBSE 2023 (55/2/1)*]

Ans. Infrared waves are produced by hot bodies and vibrations of molecules. They are referred as heat waves because they are rapidly absorbed by water molecules and increase their thermal energy and heat them.

Uses:

(*i*) Dehydration of fruits.

(*ii*) In greenhouse Effect.

(*iii*) In remote switches. [*any two*]

Q. 11. (*a*) Explain briefly the fact that electromagnetic waves carry energy.

(*b*) Why do we not, feel the pressure due to sunshine? [*CBSE 2020 (55/3/1)*]

Ans. (*a*) Consider a plane perpendicular to the direction of propagation of the electromagnetic wave. If there are, on this plane, electric charges, they will be set and sustained in motion by the electric and magnetic fields of the electromagnetic wave. The charges thus acquire energy and momentum from the waves. **1**

(*b*) When the sun shines on your hand, you feel the energy being absorbed from the electromagnetic waves (your hands get warm). Electromagnetic waves also transfer momentum to your hand but because c is very large, the amount of momentum transferred is extremely small and you do not feel the pressure. **1**

[For any other alternative correct explanation also, award full 2 marks]

[***CBSE Marking Scheme 2020 (55/3/1)***]

Q. 12. How are X-rays produced? Give any two uses of these. [*CBSE 2023 (55/2/1)*]

Ans. When fast moving electrons strike a heavy target like tungsten, *X*-rays are produced.

Uses:

(*i*) Used as a diagnostic tool in medicine.

(*ii*) Treatment for certain forms of cancer.

(*iii*) To study crystal structure. [*any two*]

Q. 13. What is a displacement current? How is it different from a conduction current?

[*CBSE 2023 (55/3/1), (55/4/1)*]

Ans. During charging, electric flux between the plates of capacitors keeps on charging; this results in the production of a displacement current between the plates.

Mathematically, $I_d = \varepsilon_0\left(\dfrac{d\phi_E}{dt}\right)$

Conduction current is established by actual movement of free electrons through a metallic conductor while displacement current is established by polarisation of molecules of a dielectric under the influence of an external electric field.

Q. 14. Write any two characteristics of an electromagnetic wave. Why are microwaves used in radar systems? *[CBSE 2023 (55/4/1)]*

Ans. Characteristics property of EM wave:

(*i*) Transverse nature

(*ii*) Does not get deflected by electric or magnetic fields

(*iii*) Same speed in vacuum for all waves

(*iv*) No material medium required for propagation

(*v*) They get refracted, diffracted and polarised *[any two]*

Due to high wavelength and low energy dispersion during long distance communication. Thus they are used in radar system.

Short Answer Questions

Each of the following questions are of 3 marks.

Q. 1. How are electromagnetic waves produced? What is the source of energy of these waves? Write mathematical expressions for electric and magnetic fields of an electromagnetic wave propagating along the *z*-axis. Write any two important properties of electromagnetic waves. *[CBSE North 2016]*

Ans. EM waves are produced by oscillating charged particle.

Mathematical expression for electromagnetic waves travelling along *z*-axis:

$E_x = E_0 \sin(kz - \omega t)$ and [For electric field]

$B_y = B_0 \sin(kz - \omega t)$ [For magnetic field]

Properties

(*i*) Electromagnetic waves have oscillating electric and magnetic fields along mutually perpendicular directions.

(*ii*) They have transverse nature.

Q. 2. Arrange the following electromagnetic waves in the order of their increasing wavelength:

(*a*) γ-rays **(*b*) Microwaves**

(*c*) X-rays **(*d*) Radiowaves**

How are infra-red waves produced? What role does infra-red radiation play in (*i*) maintaining the earth's warmth and (*ii*) physical therapy? *[CBSE Panchkula 2015]*

Ans. γ-rays < X-rays < Microwaves < Radiowaves

Infra-red waves are produced by the vibration of atoms and molecules.

(*i*) **Maintaining Earth's Warmth:** Infrared rays are absorbed by the earth's surface and reradiated as longer wave length infrared rays. These radiations are trapped by green house gases such as CO_2 and maintain earth's warmth.

(*ii*) **Physical Therapy:** Infrared rays are easily absorbed by water molecules present in body. After absorption, their thermal motion increases causing heating which is used as physical therapy.

Q. 3. When an ideal capacitor is charged by a *dc* battery, no current flows. However, when an *ac* source is used, the current flows continuously. How does one explain this, based on the concept of displacement current? *[CBSE Delhi 2012]*

Ans. When an ideal capacitor is charged by *dc* battery, charge flows (momentarily) till the capacitor gets fully charged.

When an *ac* source is connected then conduction current $I_c = \frac{dq}{dt}$ keep on flowing in the connecting wire. Due to changing current, charge deposited on the plates of the capacitor changes with time. This causes change in electric field between the plates of the capacitor which causes the electric flux to change and gives rise to a displacement current in the region between the plates of the capacitor.

As we know, displacement current

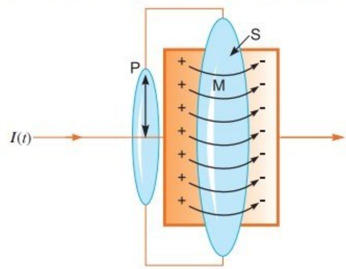
$$I_d = \varepsilon_0 \frac{d\phi_E}{dt}$$

and $\quad I_d = I_c$ at all instants.

Q. 4. Why does a galvanometer when connected in series with a capacitor show a momentary deflection, when it is being charged or discharged?

How does this observation lead to modifying the Ampere's circuital law? Hence write the generalised expression of Ampere's law. [*CBSE (F) 2015*]

Ans. During charging or discharging of the capacitor, displacement current between the plates is produced. Hence, circuit becomes complete and galvanometer shows momentary deflection.



According to Ampere's circuital Law

$$\oint \vec{B}.\vec{dl} = \mu_0 I$$

At surface P, $\quad \oint \vec{B}.\vec{dl} = \mu_0 I_c$

At surface S, $\quad \oint \vec{B}.\vec{dl} = 0$

$\therefore \quad \oint_p \vec{B}.\vec{dl} \neq \oint_s \vec{B}.\vec{dl}$

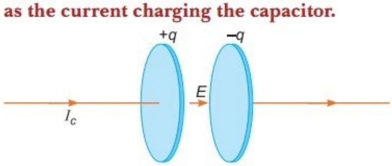
This contradicts Ampere's circuital law. This law must be missing something. Hence the law needs modification.

Modified form of Ampere's circuital law

$$\oint \vec{B}.\vec{dl} = \mu_0 \left[I_c + \varepsilon_0 \frac{d}{dt} \phi_E \right]$$

Q. 5. A capacitor, made of two parallel plates each of plate area *A* and separation *d*, is being charged by an external ac source. Show that the displacement current inside the capacitor is the same as the current charging the capacitor. [*CBSE (AI) 2013*]

Ans.



In Fig. conduction current is flowing in the wires, causes charge on the plates

So, $$I_c = \frac{dq}{dt} \quad \text{...}(i)$$

According to Maxwell, displacement current between plates,

$$I_d = \varepsilon_0 \frac{d\phi_E}{dt}, \text{ where } \phi_E = \text{ Electric flux} \quad \text{...}(ii)$$

Using Gauss's theorem, if one of the plate is inside the tiffin type Gaussian surface, then

$$\phi_E = \frac{q}{\varepsilon_0}$$

So $$I_d = \varepsilon_0 \frac{d}{dt}\left(\frac{q}{\varepsilon_0}\right) \Rightarrow I_d = \frac{dq}{dt} \quad \text{...}(iii)$$

From equation (*i*) and (*iii*),

Both conduction current and displacement current are equal.

Q. 6. Write the expression for the generalised form of Ampere's circuital law. Discuss its significance and describe briefly how the concept of displacement current is explained through charging/discharging of a capacitor in an electric circuit. **[*CBSE Allahabad 2015*]**

Ans. The generalisation in Ampere's circuital law was modified by Maxwell, as

$$\oint \vec{B}.\vec{dl} = \mu_0(I_c + I_d)$$
$$= \mu_0 I_c + \mu_0 I_d = \mu_0 I_c + \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$$

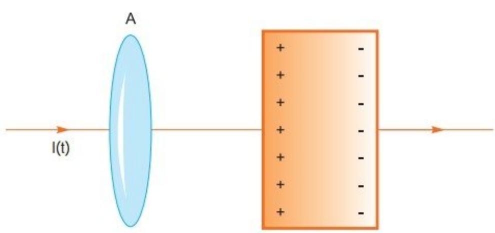
where $I_d = \varepsilon_0 \frac{d\phi_E}{dt}$ is displacement current.

Significance: This expression signifies that the source of magnetic field is not just due to the conduction current in the metallic conductors, but also due to the time rate of change of electric flux called displacement current.

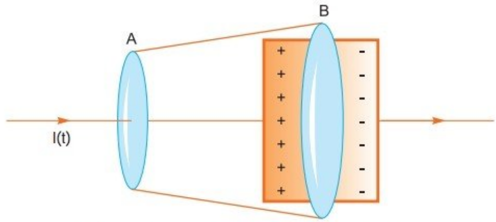
During charging and discharging of a capacitor, electric field between the plates will change. Hence there will be a change in electric flux, called displacement current, between the plates.

Q. 7. Considering the case of a parallel plate capacitor being charged, show how one is required to generalise Ampere's circuital law to include the term due to displacement current. **[*CBSE (AI) 2014*]**

Ans.



During charging capacitor C, a time varying current $I(t)$ flows through the conducting wire, so on applying Ampere's circuital law (for loop A) $\oint \vec{B}.\vec{dl} = \mu_0 I(t)$ ...(*i*)



Now we consider a pot like surface enclosing the positively charged plate and nowhere touches the conducting wire,

$$\oint \vec{B}.\vec{dl} = 0 \qquad \dots(ii)$$

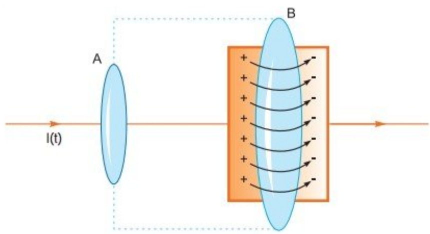
From equation (*i*) and (*ii*), we have a contradiction

If surfaces A and B forms a tiffin box, and electric field $\vec{E}$ is passing through the surface (B); constitute an electric flux

$$\phi = EA = \frac{\sigma A}{\varepsilon_0} = \frac{QA}{A\varepsilon_0} = \frac{Q}{\varepsilon_0} \qquad \dots(iii)$$

If the charge on the plate in the tiffin box is changing with time, there must be a current between the plates.

From equation (*iii*)



$$I = \frac{dQ}{dt} = \frac{d}{dt}(\varepsilon_0 \phi) = \varepsilon_0 \frac{d\phi}{dt}$$

This is the missing term in Ampere's circuital law.

The inconsistency may disappear if displacement current is included between the plates.

So generalised Ampere's circuital law can be given as

$$\oint \vec{B}.\vec{dl} = \mu_0 I_c + \mu_0 I_d = \mu_0 I_c + \mu_0 \varepsilon_0 \frac{d\phi}{dt}$$

Q. 8. **(*a*) Which one of the following electromagnetic radiations has least frequency: UV radiations, *X*-rays, Microwaves?**

(*b*) How do you show that electromagnetic waves carry energy and momentum?

(*c*) Write the expression for the energy density of an electromagnetic wave propagating in free space. **[*CBSE Bhubaneswar 2015*]**

Ans. (*a*) Microwave

(*b*) When a charge oscillates with some frequency. It produces an oscillating electric field and magnetic field in space. So, an electromagnetic wave is produced.

The frequency of the EM wave is equal to the frequency of oscillation of the charge.

Hence energy associated with the EM wave comes at the expense of the energy of the source.

If the em wave of energy U strikes on a surface and gets completely absorbed, total momentum delivery to the surface is $p = \frac{U}{E}$.

Hence em wave also carry momentum.

(*c*) The EM wave consists of oscillating electric and magnetic fields, So net energy density of EM wave is

$$U = U_E + U_B$$

$$U = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\frac{B^2}{\mu_0}$$

Q. 9. (*a*) How are electromagnetic waves produced by oscillating charges?

(*b*) State clearly how a microwave oven works to heat up a food item containing water molecules.

(*c*) Why are microwaves found useful for the radar systems in aircraft navigation?

[*CBSE (F) 2013*]

Ans. (*a*) If a charge particle oscillates with some frequency, produces an oscillating electric field in space, which produces an oscillating magnetic field, which inturn, is a source of electric field, and so on. Thus oscillating electric fields and magnetic fields regenerate each other, and an electromagnetic wave propagates in the space.

(*b*) In microwave oven, the frequency of the microwaves is selected to match the resonant frequency of water molecules so that energy from the waves get transferred efficiently to the kinetic energy of the molecules. This kinetic energy raises the temperature of any food containing water.

(*c*) Microwaves are short wavelength radio waves, with frequency of order of few GHz. Due to short wavelength, they have high penetrating power with respect to atmosphere and less diffraction in the atmospheric layers. So these waves are suitable for the radar systems used in aircraft navigation.

Q. 10. Electromagnetic waves of wavelengths λ_1, λ_2 and λ_3 are used in radar systems, in water purifiers and in remote switches of TV, respectively.

(*i*) Identify the electromagnetic waves, and

(*ii*) Write one source of each of them. **[*CBSE 2022 (55/3/1), Term-2*]**

Ans. (*i*) (*a*) Radar Systems – Microwave

(*b*) Water purifiers – Ultra Violet (UV)

(*c*) Remote switches of TV–Infrared (IR)

(*ii*)

EM-Waves	Source
(*a*) Microwave	Magnetrons or Gunn diodes
(*b*) Ultra violet (UV)	Inner shell electrons in atoms moving from one energy level to another
(*c*) Infrared (IR)	Hot bodies and molecules.

Q. 11. (*a*) Name the e.m. waves which are suitable for radar systems used in aircraft navigation. Write the range of frequency of these waves.

(*b*) If the Earth did not have atmosphere, would its average surface temperature be higher or lower than what it is now? Explain.

(*c*) An e.m. wave exerts pressure on the surface on which it is incident. Justify.

[*CBSE Sample Paper-2022, Term-2*]

Ans. (*a*) Microwaves are suitable for the radar system used in aircraft navigation.

Range of frequency of microwaves is 10^8 Hz to 10^{11} Hz.

(*b*) If the Earth did not have atmosphere, then there would be absence of greenhouse effect of the atmosphere. Due to this reason, the temperature of the earth would be lower than what it is now.

(*c*) An e.m. wave carries momentum with itself and given by

$$P = \text{Energy of wave } (U) \,/\, \text{Speed of the wave } (c)$$
$$= U/c$$

when it is incident upon a surface it exerts pressure on it.

Q. 12. Answer the following questions:

(*a*) Name the EM waves which are produced during radioactive decay of a nucleus. Write their frequency range.

(*b*) Welders wear special glass goggles while working. Why? Explain.

(*c*) Why are infrared waves often called as heat waves? Give their one application.

[*CBSE Delhi 2014*]

Ans. (*a*) EM waves : γ-rays

Range : 10^{19} Hz to 10^{23} Hz

(*b*) This is because the special glass goggles protect the eyes from large amount of UV radiations produced by welding arcs.

(*c*) Infrared waves are called heat waves because water molecules present in the materials readily absorb the infrared rays and get heated up.

Application: They are used in green houses to warm the plants.

Q. 13. Answer the following:

(*a*) Name the EM waves which are used for the treatment of certain forms of cancer. Write their frequency range.

(*b*) Thin ozone layer on top of stratosphere is crucial for human survival. Why?

(*c*) Why is the amount of the momentum transferred by the em waves incident on the surface so small? **[*CBSE Delhi 2014*]**

Ans. (*a*) X-rays or γ–rays

Range: 10^{18} Hz to 10^{22} Hz.

(*b*) Ozone layer absorbs the ultraviolet radiations from the sun and prevents it from reaching the earth's surface.

(*c*) Momentum transferred, $p = \dfrac{U}{c}$

where U = energy transferred, and c = speed of light

Due to the large value of speed of light (c), the amount of momentum transferred by the em waves incident on the surface is small.

Q. 14. Electromagnetic waves with wavelength

(*i*) λ_1 is used in satellite communication.

(*ii*) λ_2 is used to kill germs in water purifier.

(*iii*) λ_3 is used to detect leakage of oil in underground pipelines.

(*iv*) λ_4 is used to improve visibility in runways during fog and mist conditions.

(*a*) Identify and name the part of electromagnetic spectrum to which these radiations belong.

(*b*) Arrange these wavelengths in ascending order of their magnitude.

(*c*) Write one more application of each. **[*NCERT Exemplar*]**

Ans. (*a*) $\lambda_1 \rightarrow$ Microwave, $\lambda_2 \rightarrow$ UV

$\lambda_3 \rightarrow$ X-rays, $\lambda_4 \rightarrow$ Infrared

(*b*) $\lambda_3 < \lambda_2 < \lambda_4 < \lambda_1$

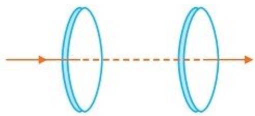
(*c*) Microwave – RADAR

UV – LASIK eye surgery

X-ray – Bone fracture identification (bone scanning)

Infrared – Optical communication

Q. 15. Figure shows a capacitor made of two circular plates each of radius 12 cm and separated by 5.0 mm. The capacitor is being charged by an external source (not shown in the figure). The charging current is constant and equal to 0.15 A.



(*a*) Calculate the capacitance and the rate of change of potential difference between the plates.

(*b*) Obtain the displacement current across the plates.

(*c*) Is Kirchhoff's first rule function rule valid at each plate of the capacitor? Explain.

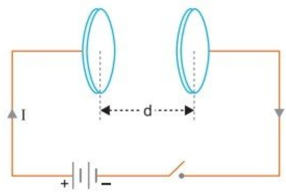
[*NCERT*]

Ans. Here, $I = 0.15$ A

$r = 12 \text{ cm} = 12 \times 10^{-2}$ m

$d = 5.0 \text{ mm} = 5 \times 10^{-3}$ m

$A = \pi r^2$



(*a*) Capacitance

$$C = \frac{\varepsilon_0 A}{d} = \frac{\varepsilon_0 \pi r^2}{d}$$

$$= \frac{8.85 \times 10^{-12} \times 22 \times (12 \times 10^{-2})^2}{7 \times 5 \times 10^{-3}}$$

$$= \frac{28036.8 \times 10^{-16}}{35 \times 10^{-3}} = 801.05 \times 10^{-13} \text{ F}$$

$$= 80.1 \times 10^{-12} \text{ F} = \mathbf{80.1\ pF}$$

Let C be the capacitance of capacitor and q the instantaneous charge on plates, then

$$q = CV$$

$$\therefore \quad \frac{dq}{dt} = C\frac{dV}{dt} \quad \Rightarrow \quad \frac{dV}{dt} = \frac{I}{C}$$

$$\therefore \quad \frac{dV}{dt} = \frac{0.15}{80.1 \times 10^{-12}} = 0.00187 \times 10^{12} \text{ Vs}^{-1} = \mathbf{1.87 \times 10^9\ Vs^{-1}}$$

(*b*) Displacement current $I_d = \varepsilon_0 A \dfrac{dE}{dt} = \varepsilon_0 A \dfrac{I}{\varepsilon_0 A} = I$ = conduction current = **0.15 A.**

(*c*) Yes, Kirchhoff's law holds at each plate of capacitor since displacement current is equal to conduction current.

Questions for Practice

1. **Choose and write the correct option in the following questions.**

   (*i*) The electromagnetic radiations used to kill germs in water purifiers are called [*CBSE 2023 (55/3/1)*]

   (*a*) Infrared waves (*b*) X-rays
   (*c*) Gamma rays (*d*) Ultraviolet rays

   (*ii*) The quantity $\sqrt{\mu_0 \varepsilon_0}$ represents

   (*a*) speed of sound (*b*) speed of light in vacuum
   (*c*) speed of electromagnetic waves (*d*) inverse of speed of light in vacuum

   (*iii*) The ratio of amplitude of magnetic field to the amplitude of electric field for an electromagnetic wave propagating in vacuum is equal to

   (*a*) the speed of light in vacuum
   (*b*) reciprocal of speed of light in vacuum
   (*c*) the ratio of magnetic permeability to the electric susceptibility of vacuum
   (*d*) unity

   (*iv*) Microwave oven acts on the principle of

   (*a*) giving rotational energy to water molecules
   (*b*) giving vibrational energy to water molecules
   (*c*) giving translational energy to water molecules
   (*d*) transferring electrons from lower to higher energy levels in water molecule

   (*v*) In a travelling plane electromagnetic wave, which of the following have zero average value? [*CBSE 2020 (55/2/3)*]

   (*a*) Magnetic energy and electric energy (*b*) Magnetic field and electric field
   (*c*) Magnetic energy and magnetic field (*d*) Electric energy and electric field

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

   (a) ***Both A and R are true and R is the correct explanation of A.***
   (b) ***Both A and R are true but R is not the correct explanation of A.***
   (c) ***A is true but R is false.***
   (d) ***A is false and R is also false.***

   Assertion (*A*) : When a charged particle moves in a circular path, it produces electromagnetic wave.

   Reason (*R*) : Charged particle has acceleration.

3. Give the ratio of velocity of the two light waves of wavelengths 4000 Å and 8000 Å travelling in vacuum. [*CBSE Sample Paper-2021)*]

4. Name the electromagnetic radiation which can be produced by klystron or a magnetron valve.

5. The oscillating electric field of an electromagnetic wave is given by

$$E_y = 30 \sin(2 \times 10^{11} t + 300\pi x)\,\text{Vm}^{-1}$$

   (*a*) Obtain the value of wavelength of the electromagnetic wave.

   (*b*) Write down the expression for oscillating magnetic field.

6. How does an oscillating charge radiate an electromagnetic wave? Give the relation between the frequency of radiated wave and the frequency of oscillating charge. [*CBSE 2020 (55/3/1)*]

7. Gamma rays and radio waves travel with the same velocity in free space. Distinguish between them in terms of their origin and the main application. [*CBSE 2020 (55/5/1)*]

8. Answer the following questions:

(*a*) Optical and radio telescopes are built on the ground while *X*-ray astronomy is possible only from satellites orbiting the Earth. Why?

(*b*) The small ozone layer on top of the stratosphere is crucial for human survival. Why?

9. A capacitor of capacitance '*C*' is being charged by connecting it across a *dc* source along with an ammeter. Will the ammeter show a momentary deflection during the process of charging? If so, how would you explain this momentary deflection and the resulting continuity of current in the circuit? Write the expression for the current inside the capacitor.

10. (*a*) Write the expression for the speed of light in a material medium of relative permittivity ε_r and relative magnetic permeability μ_r.

(*b*) Write the wavelength range and name of the electromagnetic waves which are used in (*i*) radar systems for aircraft navigation, and (*ii*) earth satellites to observe the growth of the crops. **[*CBSE 2020 (55/1/1)*]**

11. In a plane electromagnetic wave, the electric field oscillates sinusoidally at a frequency of 2.0×10^{10} Hz and amplitude 48 Vm^{-1}.

(*a*) What is the wavelength of a wave?

(*b*) What is the amplitude of the oscillating magnetic field?

(*c*) Show that the average energy density of the electric field equals the average energy density of the B field. [$c = 3 \times 10^8 \text{ ms}^{-1}$]

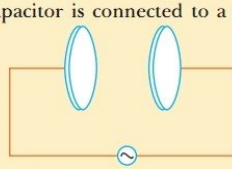
12. (*a*) Identify the part of the electromagnetic spectrum used in (*i*) radar and (*ii*) eye surgery. Write their frequency range.

(*b*) Prove that the average energy density of the oscillating electric field is equal to that of the oscillating magnetic field.

13. (*a*) A parallel plate capacitor is being charged by a time varying current. Explain briefly how Ampere's circuital law is generalized to incorporate the effect due to the displacement current.

(*b*) Find the wavelength of electromagnetic waves of frequency 6×10^{12} Hz in free space. Give its two applications.

14. A parallel plate capacitor (fig.) made of circular plates each of radius $R = 6.0$ cm has a capacitance $C = 100$ pF. The capacitor is connected to a 230 V ac supply with an angular frequency of 300 rad/s. **[*NCERT*]**



(*a*) What is the rms value of the conduction current?

(*b*) Is conduction current equal to the displacement current?

(*c*) Determine the amplitude of magnetic field induction *B* at a point 3.0 cm from the axis between the plates.

Answers

1. (*i*) (*d*)	(*ii*) (*d*)	(*iii*) (*b*)	(*iv*) (*b*)	(*v*) (*b*)
2. (*a*)	**3.** 1 : 1	**5.** (*a*) 6.67×10^{-3} m		(*b*) $10^{-7} \sin(2 \times 10^{11}t + 300\pi x)$ T
11. (*a*) 1.5×10^{-2} m	(*b*) 1.6×10^{-7} T		**14.** (*a*) 6.9 μA	(*b*) 1.63×10^{11} T

9 Ray Optics and Optical Instruments

POINTS TO REMEMBER

1. **Optics:** The study of nature and propagation of light is called optics. Ray optics deals with particle nature of light whereas wave optics considers light as a wave.

2. **Reflection of Light**

When a light ray incident on a smooth surface bounces back to the same medium, it is called reflection of light.

Laws of regular Reflection

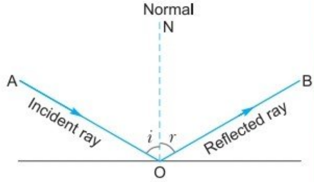
(*i*) Angle of incidence is equal to the angle of reflection.

i.e., $i = r$

(*ii*) The incident ray, the reflected ray and the normal at the point of incidence, all lie in the same plane.

These laws hold for any reflecting surface whether plane or curved.

There is no change in wavelength and frequency during reflection.



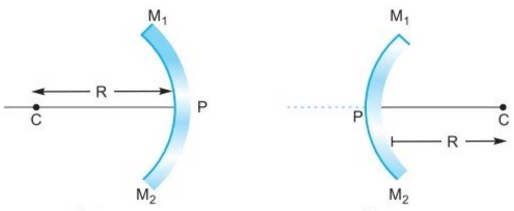
Spherical Mirror: A spherical mirror is simply a part cut off from the surface of a hollow sphere which has been made smooth and silver polished on one side.

Spherical mirrors are of two types:

(*i*) **Concave mirror:** If outer side or bulging side of the spherical surface is silver polished, it is called a concave mirror.

(*ii*) **Convex mirror:** If inner side of a spherical surface is silver polished, it is called a convex mirror.

Relation between focal length and radius of curvature: The distance between centre (C) of spherical surface and its pole (P) is called the **radius of curvature**. It is denoted by R.

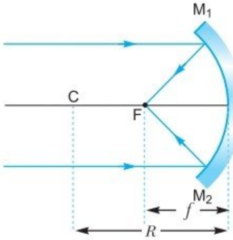


(*i*) Concave mirror (*ii*) Convex mirror

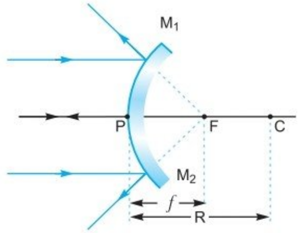
The rays parallel to the principal axis (CP) after striking the mirror meet at a point (F) (in concave mirror) or appear to be meeting at a point F (in convex mirror). This point is called the principal

focus (F) of mirror. The distance of focus (*F*) from pole (*P*) of a mirror is called the focal length of the mirror. It is denoted by f. The focal length f is half of the radius of curvature.

i.e., $\quad f = \dfrac{R}{2}$



(*i*) Concave mirror



(*ii*) Convex mirror

Mirror formula: The mirror formula is

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

where $\quad u$ = distance of object from mirror;

v = distance of image from mirror;

and $\quad f$ = focal length of mirror.

Magnification produced by mirror: The ratio of the size of image to the size of object is called linear magnification produced by the mirror.

Magnification $\quad M = \dfrac{h'}{h} = -\dfrac{v}{u} = -\dfrac{f}{u-f} = \dfrac{f-v}{f}$

Where h' is the height of image and h is the height of object.

3. Refraction of Light

When a ray of light enters from one transparent medium into another, there is a change in speed and direction of the ray in the second medium. This phenomenon is called refraction of light.

Laws of refraction:

(*i*) The incident ray, the refracted ray and the normal to the surface separating the two media, all lie in the same plane.

(*ii*) **Snell's Law:** For two media, the ratio of sine of angle of incidence to the sine of the angle of refraction is constant for a beam of particular wavelength, *i.e.*,

$$\frac{\sin i}{\sin r} = \text{constant} = \frac{n_2}{n_1} = {}_1n_2 \qquad ...(i)$$

where n_1 and n_2 are absolute refractive indices of I and II media respectively and ${}_1n_2$ is a refractive index of second (II) medium with respect to first (I) medium.

Due to principle of reversibility of light,

$$\frac{\sin r}{\sin i} = {}_2n_1 \qquad ...(ii)$$

Multiplying (*i*) by (*ii*), we get

$$1 = {}_2n_1 \times {}_1n_2 \text{ or } {}_2n_1 = \frac{1}{{}_1n_2}$$

The frequency of light remains unchanged while passing from one medium to the other.

Refractive Index:

The refractive index of a medium is defined as the ratio of speed of light in vacuum to the speed of light in a medium.

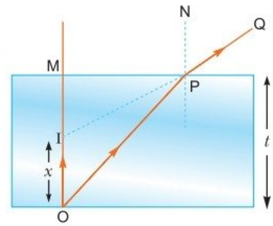
i.e., $$n = \frac{\text{Speed of light in vacuum}}{\text{Speed of light in medium}} = \frac{c}{v}$$

$$= \frac{\nu\lambda_{air}}{\nu\lambda_{medium}} = \frac{\lambda_{air}}{\lambda_{medium}}$$

λ_{air} and λ_{medium} being wavelengths of light in air and medium respectively.

$$\therefore \quad \frac{\sin i}{\sin r} = \frac{n_2}{n_1}\left(= \frac{c/v_2}{c/v_1}\right) = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$$

Formation of image due to refraction: According to Snell's law, if $n_2 > n_1$, $i > r$. That is, if a ray of light enters from rarer medium to a denser medium, it is deviated towards the normal and if $n_2 < n_1$, $i < r$ that is, if the ray of light enters from denser to a rarer medium it is deviated away from the normal.



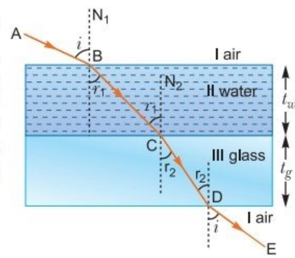
Accordingly, if the ray of light starting from object O, in the given diagram in a denser medium travels along OP, it is deviated away from the normal along PQ. The ray PQ appears to come from I. Thus I is the virtual image of O. It can be shown that

$$n = \frac{\text{Real depth}\,(OM)}{\text{Apparent depth}\,(MI)} = \frac{t}{t-x}$$

where x is the apparent shift.

$\therefore$ The apparent shift, $x = \left(1 - \frac{1}{n}\right)t$

Refraction through a number of media: Let us consider the refraction of light ray through a series of media as shown in fig. The ray AB is incident on air-water interface at an angle i. The ray is deviated in water along BC towards the normal. Then it falls on water-glass interface and is again deviated towards normal along CD. If the last medium is again air, the ray emerges parallel to the incident ray. Let r_1 and r_2 be angles of refraction in water and glass respectively, then from Snell's law,



$$\frac{\sin i}{\sin r_1} = \frac{n_w}{n_a} = {}_a n_w$$

$$\frac{\sin r_1}{\sin r_2} = \frac{n_g}{n_w} = {}_w n_g$$

$$\frac{\sin r_2}{\sin i} = \frac{n_a}{n_g} = {}_g n_a$$

$$\begin{bmatrix} n_a = \text{refractive index of air} = 1 \\ n_w = \text{refractive index of water} \\ n_g = \text{refractive index of glass} \end{bmatrix}$$

Multiplying above relations, we get ${}_a n_w \times {}_w n_g \times {}_g n_a = 1$

$${}_w n_g = \frac{1}{{}_a n_w \times {}_g n_a} = \frac{{}_a n_g}{{}_a n_w}$$

4. Critical Angle

When a ray of light is incident on the interface from denser medium to rarer medium, it is deviated away from the normal. When angle of incidence is increased, angle of refraction also increases and at a stage it becomes 90°.

The angle of incidence in denser medium for which the angle of refraction in rarer medium is 90° is called the **critical angle (C)** *for the pair of media.*

If n_r and n_d are refractive indices for rarer and denser media, then

$$\therefore \quad \frac{\sin i}{\sin r} = \frac{n_2}{n_1} \text{ gives}$$

$$\frac{\sin C}{\sin 90^\circ} = \frac{n_r}{n_d} = {}_d n_r$$

$$\sin C = {}_d n_r = \frac{1}{{}_r n_d} = \frac{1}{n}$$

where ${}_r n_d = n$ and n is the refractive index of a denser medium with respect to a rarer medium.

5. Total Internal Reflection

When angle of incidence in the denser medium is greater than the critical angle, the incident ray does not refract into a rarer medium but is reflected back into the denser medium. This phenomenon is called total *internal reflection*. **The conditions for total internal reflection are**

(*i*) The ray must travel from a denser into a rarer medium.

(*ii*) The angle of incidence $i >$ critical angle C.

The critical angle for water-air, glass-air and diamond-air interfaces are 49°, 42° and 24° respectively.

6. Spherical Lenses

There are two types of spherical lenses.

(*i*) Convex lens (Converging lens)

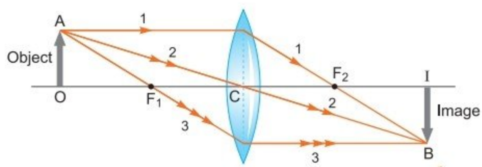
(*ii*) Concave lens (Diverging lens)

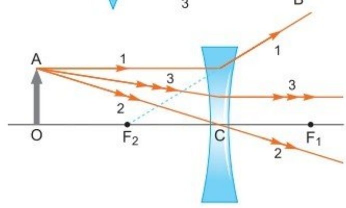
Rules of Image Formation in Lenses

(*i*) The ray incident on lens parallel to the principal axis, after refraction through the lens, passes through the second focus (in convex lens) or appear to come from second focus (in concave lens).

(*ii*) The ray incident on lens through optical centre C, after refraction, pass straight without any deviation.

(*iii*) A ray directed towards the first focus incident on the lens, after refraction becomes parallel to the principal axis.





7. Thin Lens Formula

If u and v are object and image distances from a lens of focal length f, then thin lens formula is

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

This equation holds for convex and concave lenses both, but proper signs of u, v and f are to be used according to sign convention of coordinate geometry. Focal length of a convex lens is taken as positive and of a concave lens is taken as negative.

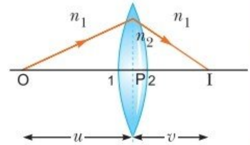
Magnification produced by a lens

$$m = \frac{h'}{h} = \frac{v}{u} = \frac{f}{u+f} = \frac{f-v}{f}$$

where h' is the size of image and h is the size of object.

8. Lens Maker's Formula

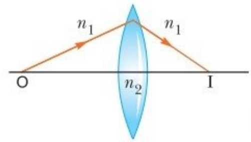
If R_1 and R_2 are the radii of curvature of first and second refracting surfaces of a thin lens of focal length f, then lens makers formula is



$$\frac{1}{f} = ({}_1n_2 - 1) \times \left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$= (n-1) \times \left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

where ${}_1n_2 = n$ is refractive index of material of lens with respect to surrounding medium.



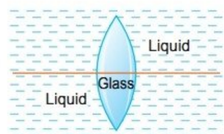
9. Power of a Lens

The power of a lens is its ability to deviate the rays towards its principal axis. It is defined as the reciprocal of focal length in metres.

Power of a lens, $P = \dfrac{1}{f(\text{in metre})}$

Its unit is diopter and is represented as 'D'.

10. Lens Immersed in a Liquid



If a lens of refractive index n_g is immersed in a liquid of refractive index n_l then its focal length (f_l) in liquid, is given by

$$\frac{1}{f_l} = ({}_ln_g - 1) \times \left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

where $\qquad {}_ln_g = \dfrac{n_g}{n_l}$

If f_a is the focal length of lens in air, then $f_l = \dfrac{n_g - 1}{\dfrac{n_g}{n_l} - 1} \times f_a$

Three cases arise:

(*i*) If $n_g > n_l$, then f_l and f_a are of same sign but $f_l > f_a$.
That is, the nature of lens remains unchanged, but its focal length increases and hence the power of lens decreases. In other words the convergent lens becomes less convergent and divergent lens becomes less divergent.

(*ii*) If $n_g = n_l$, then $f_l = \infty$. That is, the lens behaves as a glass plate.

(*iii*) If $n_g < n_l$, then f_l and f_a have opposite signs.
That is, the nature of lens changes. A convergent lens becomes divergent and vice versa.

11. Thin Lenses in Contact

If two or more lenses of focal lengths f_1, f_2 are placed in contact, then their equivalent focal length F is given by

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} + \ldots$$

The power of combination

$$P = P_1 + P_2 + \ldots$$

12. Refraction Through a Prism

A prism is a transparent medium enclosed by two plane refracting surfaces. Let *EF* be the monochromatic ray incident on the face *PQ* of prism *PQR* of refracting angle *A* at angle of incidence i_1. This ray is refracted along *FG*, r_1 being angle of refraction. The ray *FG* is incident on the face *PR* at angle of incidence r_2 and is refracted in air along *GH*. Thus *GH* is the emergent ray and i_2 is the angle of emergence. The angle between incident ray *EF* and emergent ray *GH* is called *angle of deviation* δ.

For a prism if *A* is the refracting angle of prism, then

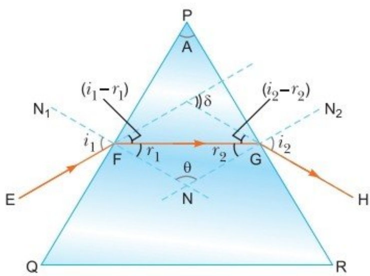
$$r_1 + r_2 = A \qquad \ldots(i)$$

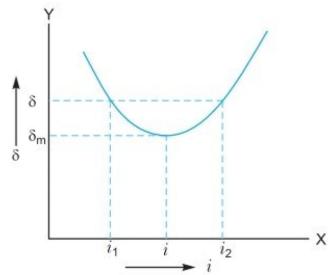
and $$i_1 + i_2 = A + \delta \qquad \ldots(ii)$$

Clearly, deviation $\delta = i_1 + i_2 - A$, i_1 and i_2 may be inter-changed, therefore, there are two values of angles of incidence for same deviation δ.

If *n* is the refractive index of material of prism, then from Snell's law

$$n = \frac{\sin i_1}{\sin r_1} = \frac{\sin i_2}{\sin r_2}.$$





If angle of incidence is changed, the angle of deviation δ changes as shown in fig. For a particular angle of incidence the deviation is minimum. This is called *angle of minimum deviation* δ_m.

Minimum deviation: At minimum deviation the refracted ray within a prism is parallel to the base. Therefore,

$$i_1 = i_2 = i \text{ (say)}$$
$$r_1 = r_2 = r \text{ (say)}$$

Then from equations (*i*) and (*ii*),

$$r + r = A \quad \text{or} \quad r = A/2$$

$$i + i = A + \delta_m \quad \text{or} \quad i = \frac{A + \delta_m}{2}$$

$\therefore$ The refractive index of material of prism

$$n = \frac{\sin i}{\sin r} = \frac{\sin\left(\frac{A + \delta_m}{2}.\right)}{\sin (A/2)}$$

For a thin prism, *viz.* $A \le 10°$

$$\delta_m = (n - 1) A.$$

13. Optical Instruments (Microscopes and Telescopes)

A microscope is an optical instrument to see very small objects.

(*i*) **Simple Microscope:** It consists of a convex lens of small focal length *f*.

If β = angle subtended by an image on eye

α = angle subtended by an object on eye, when object is at a distance of distinct vision (D)

Magnifying power,

$$M = \frac{\beta}{\alpha} = \frac{D}{v}\left(1 + \frac{v}{f}\right)$$

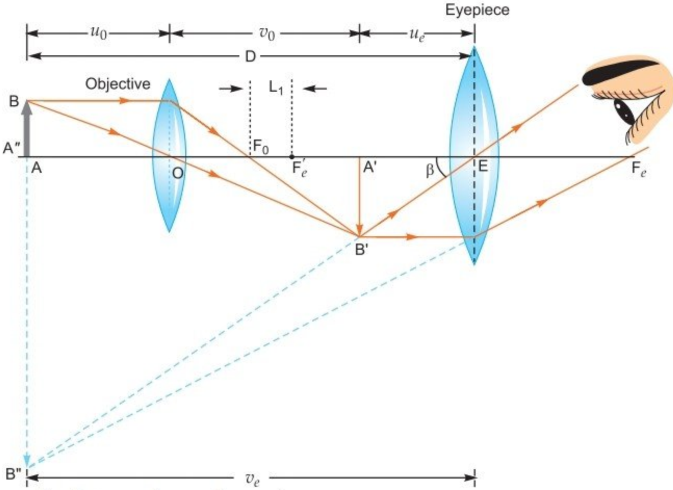
If the final image is at ∞, $v = \infty$ then $M = \frac{D}{f}$

If the final image is at a distance of distinct vision, $v = D, M = 1 + \frac{D}{f}$.

***(ii)* Compound Microscope:** A compound microscope essentially consists of two co-axial convex lenses of small focal lengths. The lens facing the object is called an objective lens while that towards eye is called the eye lens (eyepiece).

$\therefore$ Magnifying power of microscope,

$$M = \frac{\beta}{\alpha}(= m_o \times m_e) = \frac{v_o D}{u_o v_e}\left(1 + \frac{v_e}{f_e}\right)$$



Separation between lenses, $L = v_0 + u_e$

Special cases:

(*a*) When final image is formed at a distance of distinct vision, $v_e = D$

$$M = -\frac{v_o}{u_o}\left(1 + \frac{D}{f_e}\right) \text{ and } L = v_0 + u_e$$

The distance between second focal point of objective and first focal point of eye lens is called the tube length denoted by L,then

$$\frac{v_o}{u_o} = \frac{L}{f_0}$$

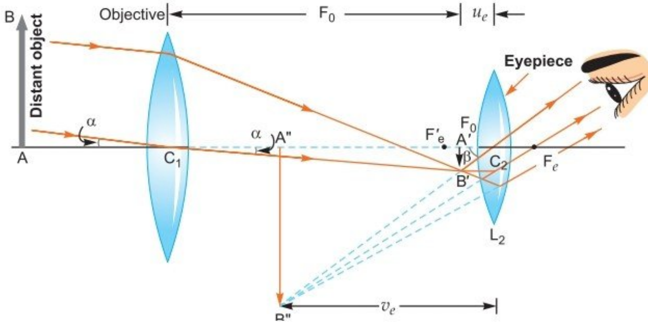
So, $$M = -\frac{L}{f_0}\left(1 + \frac{D}{f_e}\right)$$

(*b*) When final image is formed at infinity, $v_e = \infty$, then

$$M = -\frac{v_o}{u_o} \times \frac{D}{f_e}$$

$$= -\frac{L}{f_o} \cdot \frac{D}{f_e} \text{ and } L = v_o + f_e$$

(iii) **Astronomical Telescope (Refracting Telescope):** It is used to see magnified images of distant objects. An astronomical telescope essentially consists of two co-axial convex lenses. The lens facing the object has a large focal length and a large aperture and is called objective, while the lens towards eye has a small focal length and small aperture and is called eye lens.



The magnifying power of telescope is

$$M = \frac{\text{Angle subtended by final image at eye}}{\text{Angle subtended by object on eye}} = \frac{\beta}{\alpha}$$

$$= (m_0 \times m_e) = -\frac{f_0}{f_e}\left(1 + \frac{f_e}{v_e}\right)$$

and Length of telescope, $L = f_0 + u_e$

where u_e = distance of real image from eye lens

v_e = distance of final image A′ B′ from eye lens

f_0 = focal length of objective, f_e = focal length of eye lens

α = angle subtended by an object at eye = $\dfrac{h}{f_0}$

β = angle subtended by an image at eye = $\dfrac{h}{f_e}$

Special cases:

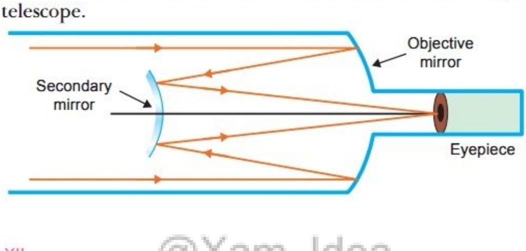
(*a*) When final image is formed at a distance of distinct vision, then $v_e = D$

$$M = -\frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right) \text{ and } L = f_o + u_e$$

(*b*) When final image is formed at infinity, then $v_e = \infty$

$$M = -\frac{f_o}{f_e} \text{ and } L = f_o + f_e$$

Reflecting Telescope: In this telescope, a concave mirror is used as an objective in place of a convex lens. It is free from chromatic aberration and it has larger resolving power than refracting telescope.



14. Magnifying Power of Optical Instruments

The size of an object depends on the angle subtended by the object on eye. This angle is called visual angle. Greater the visual angle, greater the size of object. Stars are bigger than sun; but appear smaller because stars are much farther away than sun and they subtend smaller angles on eye.

The angle subtended on eye may be increased by using telescopes and microscopes. The telescopes and microscopes form the image of an object. The image subtends larger angle on eye; hence the object appears big. The magnification produced by optical instrument (telescope/microscope) is defined as the ratio of angle (β) subtended by image on eye and the angle (α) subtended by object on eye.

i.e., Angular magnification, $M = \dfrac{\beta}{\alpha}$

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

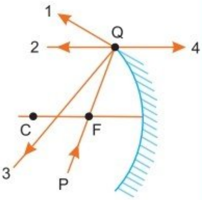
Multiple Choice Questions

Choose and write the correct option(s) in the following questions.

1. For a concave mirror of focal length '*f*', the minimum distance between the object and its real image is: **[*CBSE 2023 (55/1/1)*]**

(*a*) zero (*b*) *f* (*c*) 2*f* (*d*) 4*f*

2. The direction of ray of light incident on a concave mirror is shown by *PQ* while directions in which the ray would travel after reflection is shown by four rays marked 1, 2, 3 and 4 (Fig. given alongside). Which of the four rays correctly shows the direction of reflected ray? **[*NCERT Exemplar*]**



(*a*) 1 (*b*) 2

(*c*) 3 (*d*) 4

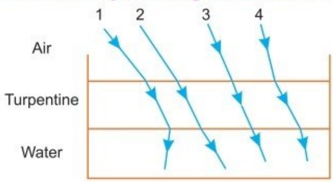
3. A ray of monochromatic light propagating in air, is incident on the surface of water. Which of the following will be the same for the reflected and refracted rays? **[*CBSE 2023 (55/2/1)*]**

(*a*) Energy carried (*b*) Speed (*c*) Frequency (*d*) Wavelength

4. A short pulse of white light is incident from air to a glass slab at normal incidence. After travelling through the slab, the first colour to emerge is **[*NCERT Exemplar*]**

(*a*) blue (*b*) green (*c*) violet (*d*) red

5. The optical density of turpentine is higher than that of water while its mass density is lower. Figure shows a layer of turpentine floating over water in a container. For which one of the four rays incident on turpentine in the figure, the path shown is correct? **[*NCERT Exemplar*]**

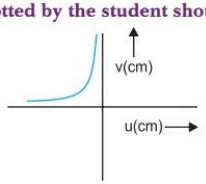


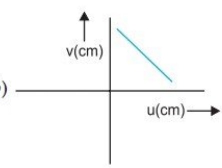
(*a*) 1 (*b*) 2 (*c*) 3 (*d*) 4

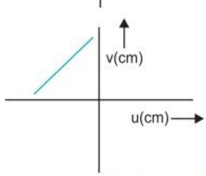
6. A beam of light travels from air into a medium. Its speed and wavelength in the medium are 1.5×10^8 ms^{-1} and 230 nm respectively. The wavelength of light in air will be **[*CBSE 2023(55/2/1)*]**

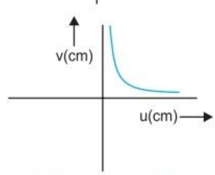
(*a*) 230 nm (*b*) 345 nm (*c*) 460 nm (*d*) 690 nm

7. **Transmission of light in optical fibre is due to**
   (*a*) scattering
   (*b*) diffraction
   (*c*) refraction
   (*d*) multiple total internal reflection
8. **You are given four sources of light each one providing a light of a single colour – red, blue, green and yellow. Suppose the angle of refraction for a beam of yellow light corresponding to a particular angle of incidence at the interface of two media is 90°. Which of the following statements is correct if the source of yellow light is replaced with that of other lights without changing the angle of incidence?** **[*NCERT Exemplar*]**
   (*a*) The beam of red light would undergo total internal reflection.
   (*b*) The beam of red light would bend towards normal while it gets refracted through the second medium.
   (*c*) The beam of blue light would undergo total internal reflection.
   (*d*) The beam of green light would bend away from the normal as it gets refracted through the second medium.
9. **Which of the following is not due to total internal reflection ?**
   (*a*) Working of optical fibre
   (*b*) Difference between apparent and real depth of a pond
   (*c*) Mirage on hot summer days
   (*d*) Brilliance of diamond
10. **An object approaches a convergent lens from the left of the lens with a uniform speed 5 m/s and stops at the focus. The image** **[*NCERT Exemplar*]**
   (*a*) moves away from the lens with an uniform speed 5 m/s.
   (*b*) moves away from the lens with an uniform accleration.
   (*c*) moves away from the lens with a non-uniform acceleration.
   (*d*) moves towards the lens with a non-uniform acceleration.
11. **The radius of curvature of the curved surface of a plano-convex lens is 20 cm. If the refractive index of the material of the lens be 1.5, it will** **[*NCERT Exemplar*]**
   (*a*) act as a convex lens only for the objects that lie on its curved side.
   (*b*) act as a concave lens for the objects that lie on its curved side.
   (*c*) act as a convex lens irrespective of the side on which the object lies.
   (*d*) act as a concave lens irrespective of side on which the object lies.
12. **A student measures the focal length of a convex lens by putting an object pin at a distance '*u*' from the lens and measuring the distance '*v*' of the image pin. The graph between '*u*' and '*v*' plotted by the student should look like**

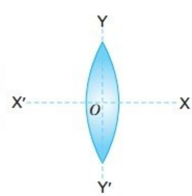
(*a*)


(*b*)


(*c*)


(*d*)


13. **An equiconvex lens is cut into two halves along (*i*) *XOX*' and (*ii*) *YOY*' as shown in the figure. Let f, f' and f'' be the of the focal lengths of complete lens of each half in case (*i*) and of each half in case (*ii*) respectively. Choose the correct statement from the following :**



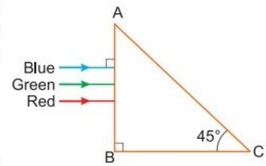
   (*a*) $f' = 2f$ and $f'' = f$
   (*b*) $f' = f$ and $f'' = f$
   (*c*) $f' = 2f$ and $f'' = 2f$
   (*d*) $f' = f$ and $f'' = 2f$

14. **A ray of light incident at an angle θ on a refracting face of a prism emerges from the other face normally. If the angle of the prism is 5° and the prism is made of a material of refractive index 1.5, the angle of incidence is** [*NCERT Exemplar*]

(*a*) 7.5° (*b*) 5° (*c*) 15° (*d*) 2.5°

15. **A beam of light consisting of red, green and blue colours is incident on a right angled prism. The refractive index of the material of the prism for the above red, green and blue wavelengths are 1.39, 1.44 and 1.47 respectively.**

The prism will



(*a*) not separate the three colours at all

(*b*) separate the red colour part from the green and blue colours

(*c*) separate the blue colour part from the red and green colours

(*d*) separate all the three colours from one another

16. **A thin prism having refracting angle 10° is made of glass of refractive index 1.42. This prism is combined with another thin prism of glass of refractive index 1.7. This combination produces dispersion without deviation. This refracting angle of second prism should be**

(*a*) 6° (*b*) 8° (*c*) 10° (*d*) 4°

17. **A biconcave lens of power *P* vertically splits into two identical plano concave parts. The power of each part will be** [*CBSE 2020 (55/5/1)*]

(*a*) $2P$ (*b*) $P/2$ (*c*) P (*d*) $P/\sqrt{2}$

18. **A biconvex lens of glass having refractive index 1.47 is immersed in a liquid. It becomes invisible and behaves as a plane glass plate. The refractive index of the liquid is** [*CBSE 2020 (55/1/1)*]

(*a*) 1.47 (*b*) 1.62 (*c*) 1.33 (*d*) 1.51

19. **For a glass prism, the angle of minimum deviation will be smallest for the light of** [*CBSE 2020 (55/1/1)*]

(*a*) red colour (*b*) blue colour (*c*) yellow colour (*d*) green colour

20. **If the focal length of objective lens is increased then magnifying power of**

(*a*) microscope will increase but that of telescope decrease

(*b*) microscope and telescope both will increase

(*c*) microscope and telescope both will decrease

(*d*) microscope will decrease but that of telescope will increase

21. **Four lenses of focal length ±15 cm and ±150 cm are available for making a telescope. To produce the largest magnification, the focal length of the eyepiece should be**

(*a*) +15 cm (*b*) +150 cm (*c*) –150 cm (*d*) –15 cm

22. **The magnifying power of a telescope is 9. When it is adjusted for parallel rays the distance between the objective and eyepiece is 20 cm. The focal length of lenses are**

(*a*) 11 cm, 9 cm (*b*) 10 cm, 10 cm (*c*) 15 cm, 5 cm (*d*) 18 cm, 2 cm

23. **The focal length of the objective of a compound microscope is** [*CBSE 2020 (55/1/3)*]

(*a*) greater than the focal length of eyepiece

(*b*) lesser than the focal length of eyepiece

(*c*) equal to the focal length of eyepiece

(*d*) equal to the length of its tube

24. **Larger aperture of objective lens in an astronomical telescope** [*CBSE 2020 (55/1/1)*]

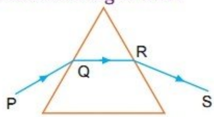
(*a*) increases the resolving power of telescope.

(*b*) decreases the brightness of the image.

(*c*) increases the size of the image.

(*d*) decreases the length of the telescope.

25. **A ray of light is incident on an equilateral glass prism placed on a horizontal table. For minimum deviation which of the following is true?**



(*a*) *PQ* is horizontal
(*b*) *QR* is horizontal
(*c*) *RS* is horizontal
(*d*) Either *PQ* or *RS* is horizontal

26. **A thin glass (refractive index 1.5) lens has optical power of – 5 D in air. Its optical power in liquid with refractive index 1.7 will be**

(*a*) – 1 D (*b*) + 1 D (*c*) – 25 D (*d*) + 25 D

27. **Refractive index of water is $\frac{5}{3}$. A light source is placed in water at a depth of 4 m. Then what must be the minimum radius of disc placed at water surface so that the light of source can be stopped?** [*HOTS*]

(*a*) 3 m (*b*) 4 m (*c*) 5 m (*d*) infinite

Answers

1. (*a*)	2. (*b*)	3. (*c*)	4. (*d*)	5. (*b*)	6. (*c*)	7. (*d*)
8. (*c*)	9. (*b*)	10. (*c*)	11. (*c*)	12. (*a*)	13. (*d*)	14. (*a*)
15. (*b*)	16. (*a*)	17. (*b*)	18. (*a*)	19. (*a*)	20. (*d*)	21. (*a*)
22. (*d*)	23. (*b*)	24. (*a*)	25. (*b*)	26. (*b*)	27. (*a*)	

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(a) ***Both A and R are true and R is the correct explanation of A.***
(b) ***Both A and R are true but R is not the correct explanation of A.***
(c) ***A is true but R is false.***
(d) ***A is false and R is also false.***

1. **Assertion (*A*)** : Diamond glitters brilliantly.
Reason (*R*) : Diamond reflects sunlight strongly.

2. **Assertion (*A*)** : A convex mirror cannot form real images.
Reason (*R*) : Convex mirror converges the parallel rays that are incident on it.
[*CBSE Sample Paper-2021*]

3. **Assertion (*A*)** : In a telescope, objective lens has greater focal length than eye piece but in a microscope objective has smaller focal length than eye piece. By inverting a telescope, a microscope cannot be formed.
Reason (*R*) : The difference in focal lengths of objective and eye lens in telescope is much larger than in microscope.

4. **Assertion (*A*)** : A convex lens of focal length 30 cm can't be used as a simple microscope in normal setting.
Reason (*R*) : For normal setting, the angular magnification of simple microscope is $M = D/f$.
[*CBSE Sample Paper-2021*]

5. **Assertion** (*A*) : For observing traffic at back, the driver mirror is convex mirror.

   Reason (*R*) : A convex mirror has much larger field of view than a plane mirror.

6. **Assertion** (*A*) : In astronomical telescope, the objective lens is of large aperture.

   Reason (*R*) : Larger is the aperture, smaller is the magnifying power.

7. **Assertion** (*A*) : The speed of light in glass depends on colour of light.

   Reason (*R*) : The speed of light in glass $v_g = \frac{c}{n_g}$, the refractive index (n_g) of glass is different for different colours.

8. **Assertion** (*A*) : A ray of light is incident from outside on a glass sphere surrounded by air. This ray may suffer total internal reflection at second interface.

   Reason (*R*) : If a ray of light goes from denser to rarer medium, it bends away from the normal. [*AIIMS 2017*]

9. **Assertion** (*A*) : In compound microscope, the objective lens is taken of small focal length.

   Reason (*R*) : This increases the magnifying power of microscope.

10. **Assertion** (*A*) : If a convex lens is kept in water, its convergence power decreases.

    Reason (*R*) : The refractive index of convex lens relative to water is less than that relative to air.

Answers

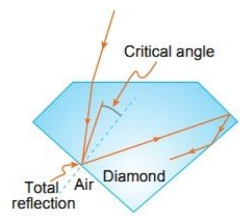
1. (*c*) **2.** (*c*) **3.** (*a*) **4.** (*b*) **5.** (*a*) **6.** (*c*) **7.** (*a*)
8. (*a*) **9.** (*b*) **10.** (*a*)

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Case-based/Passage-based Questions

Read the paragraph given below and answer the questions that follow:

1. **Sparking Brilliance of Diamond:** The total internal reflection of the light is used in polishing diamonds to create a sparking brilliance. By polishing the diamond with specific cuts, it is adjusted so that the most of the light rays approaching the surface are incident with an angle of incidence more than critical angle. Hence, they suffer multiple reflections and ultimately come out of diamond from the top. This gives the diamond a sparking brilliance. [*CBSE Sample Paper-2021*]



   (*i*) **Light cannot easily escape a diamond without multiple internal reflections. This is because**

   (*a*) its critical angle with reference to air is too large.
   (*b*) its critical angle with reference to air is too small.
   (*c*) the diamond is transparent.
   (*d*) rays always enter at angle greater than critical angle.

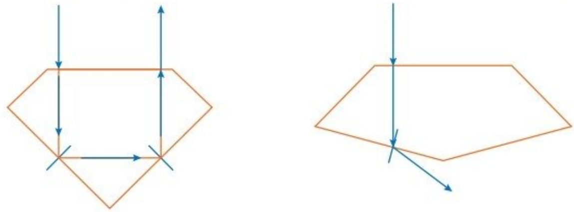
   (*ii*) **The critical angle for a diamond is 24.4°. Then its refractive index is**

   (*a*) 2.42 (*b*) 0.413
   (*c*) 1 (*d*) 1.413

   (*iii*) **The basic reason for the extraordinary sparkle of suitably cut diamond is that**

   (*a*) it has low refractive index
   (*b*) it has high transparency
   (*c*) it has high refractive index
   (*d*) it is very hard

(*iv*) **The following diagram shows same diamond cut in two different shapes.**



The brilliance of diamond in the second diamond will be:

(*a*) less than the first (*b*) greater than first

(*c*) same as first (*d*) will depend on the intensity of light

OR

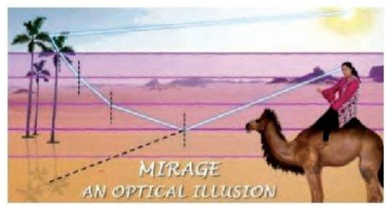
A diamond is immersed in a liquid with a refractive index greater than water. Then the critical angle for total internal reflection will

(*a*) depend on the nature of the liquid (*b*) decrease

(*c*) remain the same (*d*) increase

2. **Mirage in Deserts:**

To a distant observer, the light appears to be coming from somewhere below the ground. The observer naturally assumes that light is being reflected from the ground, say, by a pool of water near the tall object.



Such inverted images of distant tall objects cause an optical illusion to the observer. This phenomenon is called mirage. This type of mirage is especially common in hot deserts.

[*CBSE Sample Paper-2022, Term-2*]

(*i*) **Which of the following phenomena is prominently involved in the formation of mirage in deserts?**

(*a*) Refraction, Total internal Reflection

(*b*) Dispersion and Refraction

(*c*) Dispersion and scattering of light

(*d*) Total internal Reflection and diffraction

(*ii*) **A diver at a depth 12 m inside water $\left({}^{a}\mu_{w} = \frac{4}{3}\right)$ sees the sky in a cone of semi- vertical angle**

(*a*) $\sin^{-1}\frac{4}{3}$ (*b*) $\tan^{-1}\frac{4}{3}$

(*c*) $\sin^{-1}\frac{3}{4}$ (*d*) 90°

(*iii*) **In an optical fibre, if n_1 and n_2 are the refractive indices of the core and cladding, then which among the following, would be a correct equation?**

(*a*) $n_1 < n_2$ (*b*) $n_1 = n_2$ (*c*) $n_1 << n_2$ (*d*) $n_1 > n_2$

(*iv*) **A diamond is immersed in such a liquid which has its refractive index with respect to air as greater than the refractive index of water with respect to air. Then the critical angle of diamond-liquid interface as compared to critical angle of diamond -water interface will**

(*a*) depend on the nature of the liquid only (*b*) decrease

(*c*) remain the same (*d*) increase

(*iii*) **Which of the following is not correct in the context of a compound microscope?**

(*a*) Both the lenses are of short focal lengths.

(*b*) The magnifying power increases by decreasing the focal lengths of the two lenses.

(*c*) The distance between the two lenses is more than $(f_o + f_e)$.

(*d*) The microscope can be used as a telescope by interchanging the two lenses.

(*iv*) **A compound microscope consists of an objective of 10X and an eye-piece of 20X. The magnification due to the microscope would be**

(*a*) 2 (*b*) 10

(*c*) 30 (*d*) 200

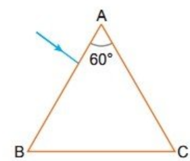
OR

The focal lengths of objective and eye-piece of a compound microscope are 1.2 cm and 3.0 cm respectively. The object is placed at a distance of 1.25 cm from the objective. If the final image is formed at infinity, the magnifying power of the microscope would be

(*a*) 100 (*b*) 150

(*c*) 200 (*d*) 250

4. **Refraction through Prism:** Strontium titanate is a rare oxide a natural mineral found in Siberia. It is used as a substitute for diamond because its refractive index and critical angle are 2.41 and 24.5°, respectively, which are approximately equal to the refractive index and critical angle of diamond. It has all the properties of diamond. Even an expert jeweller is unable to differentiate between diamond and strontium titanate. A ray of light is incident normally on one face of an equilateral triangular prism *ABC* made of strontium titanate.



[*CBSE 2023 (55/1/1), Modified*]

(*i*) **The necessary conditions for total internal reflection is**

(*a*) the angle of incidence in denser medium must be smaller than the critical angle for two media

(*b*) the angle of refraction in denser medium must be greater than the critical angle for two media

(*c*) the angle of incidence in denser medium must be greater than the critical angle for two media

(*d*) none of these

(*ii*) **The speed of light in a medium whose critical angle is 30° is**

(*a*) 3×10^8 m/s (*b*) 2×10^8 m/s

(*c*) 1.5×10^8 m/s (*d*) 2.5×10^8 m/s

(*iii*) **Dispersion power depends upon**

(*a*) height of the prism (*b*) angle of prism

(*c*) material of prism (*d*) the shape of prism

(*iv*) **A ray of light incident at an angle θ on refracting face of a prism emerges from the other normally. If the angle of the prism is 30° and the prism is made up of a material of refractive index 1.5, the angle of incidence is**

(*a*) 30° (*b*) 45°

(*c*) 60° (*d*) 90°

OR

When light rays are incident on a prism at an angle of 45°, the minimum deviation is obtained. If refractive index of prism is $\sqrt{2}$, then the angle of prism will be

(*a*) 60° (*b*) 40°

(*c*) 50° (*d*) 30°

5. **Lens Maker's Formula:** The lens maker's formula is useful to design lenses of desired focal lengths using surfaces of suitable radii of curvature. The focal length also depends on the refractive index of the material of the lens and the surrounding medium. The refractive index depends on the wavelength of the light used. The power of a lens is related to its focal length.

[*CBSE 2023 (55/4/1), Modified*]

(*i*) How will the power of lens affected with an increase of wave length of light?

(*a*) increases (*b*) decreases
(*c*) first increases then decreases (*d*) first decreases then increases

(*ii*) The radius of curvatures of two surface of a convex lens is *R*. For what value of μ of its material will its focal length become equal to *R*?

(*a*) 1 (*b*) 1.5
(*c*) 2 (*d*) infinite

(*iii*) An object is immersed in a fluid. In order that the object becomes invisible, it should

(*a*) behave as perfect reflector
(*b*) absorb all the light falling on it
(*c*) have refractive index 1
(*d*) have refractive index exactly matching with that of the surrounding fluid

(*iv*) An object is placed in front of a Lens Which forms its erect image of magnification 3. The Power of the lens is 5D. Calculate the distance of the image from the lens.

(*a*) – 40 cm (*b*) 40 cm
(*c*) – 80 cm (*d*) 80 cm

OR

The focal length of a concave lens of $\mu = 1.5$ is 20 cm is air. It is completely immersed in water $\mu = \frac{4}{3}$. Its focal length in water will be

(*a*) 20 cm (*b*) 40 cm (*c*) 60 cm (*d*) 80 cm

Explanations

1. (*i*) (*b*) Its critical angle of light with reference to air is too small.

(*ii*) (*a*) Given critical angle, $i_c = 24.4°$

Refractive index, $n = \frac{1}{\sin i_c} = \frac{1}{\sin 24.4°}$

$\therefore \quad n = 2.42$

(*iii*) (*c*) Because it has high refractive index.

(*iv*) (*a*) The brilliance of second diamond will be less than that of first because critical angle for first diamond w.r.t. air is very small as compared to second diamond. So, more TIR takes place in first diamond as compared to the second.

OR

(*d*) increase (*i.e.*, $\sin i_c = \frac{1}{n}$)

2. (*i*) (*a*) Refraction, Total internal reflection

(*ii*) (*c*) By Snell's Law,

$$^a\mu_w = \frac{1}{\sin C} \qquad \left[{}^a\mu_w = \frac{4}{3} \text{ (given)}\right]$$

$$\Rightarrow \quad \sin C = \frac{1}{^a\mu_w}$$

$$\therefore \quad C = \sin^{-1}\left(\frac{1}{^a\mu_w}\right) = \sin^{-1}\left(\frac{3}{4}\right)$$

(*iii*) (*d*) The refractive index of the core should be greater than the refractive index of the cladding. (*i.e.*, $n_1 > n_2$)

(*iv*) (*d*) By Snell's Law, ${}^{l}\mu_d = \frac{1}{\sin C} = \frac{\mu_d}{\mu_l}$, ${}^{w}\mu_d = \frac{1}{\sin C'} = \frac{\mu_d}{\mu_w}$

$$\mu_l > \mu_w$$

Thus, $C > C'$ (increases)

OR

(*b*) By Snell's Law, ${}^{1}\mu_2 = \frac{1}{\sin C'}$

$$\sin C' = \frac{1.44}{1.68} = 0.8571$$

$\Rightarrow \quad C' = 59°$

Total internal reflection will occur if the angle $i' = i'_c$,

i.e., if $i' > 59°$ or when $r < r_{max}$, where $r_{max} = 90° - 59° = 31°$.

Using Snell's law,

$$\frac{\sin i_{max}}{\sin r_{max}} = 1.68$$

or $\quad \sin i_{max} = 1.68 \times \sin r_{max}$

$$= 1.68 \times \sin 31°$$

$$= 1.68 \times 0.5150 = 0.8662$$

$\therefore \quad i_{max} = 60°$

Thus all incident rays which make angles in the range $0 < i < 60°$ with the axis of the pipe will suffer total internal reflections in the pipe.

3. (*i*) (*b*) Real, Virtual

(*ii*) (*a*) Magnifying power of compound microscope,

$$M = -\frac{v_0}{u_0}\left(1 + \frac{D}{f_e}\right) \text{ [For final image formed at near point]}$$

$$M = -\frac{L}{f_0}\left(\frac{D}{f_e}\right) \text{ [For final image formed at infinity]}$$

Hence M does not depends upon the aperture of the objective and the eye-piece.

(*iii*) (*d*) The microscope can be used as a telescope by interchanging the two lenses.

(*iv*) (*d*) Magnifying power,

$$M = M_0 \times M_e$$

$$= 10 \times 20 = 200$$

OR

(*c*) Given, $f_o = 1.2$ cm, $f_e = 3.0$ cm, $u_o = -1.25$ cm

Using lens formula at objective lens.

$$\frac{1}{f_0} = \frac{1}{v_0} - \frac{1}{u_0}$$

$$\Rightarrow \quad \frac{1}{v_0} = \frac{1}{f_0} + \frac{1}{u_0} = \frac{1}{1.2} - \frac{1}{1.25} = \frac{1.25 - 1.2}{1.2 \times 1.25} = \frac{0.05}{1.2 \times 1.25} = \frac{1}{30}$$

$\therefore \quad v_0 = 30$ cm.

When final image formed at infinity,

$$M = -\frac{v_0}{u_0} \times \frac{D}{f_e} = \frac{-30}{-1.25} \times \frac{25}{3} = 200$$

4. (*i*) (*c*) For TIR, $i > i_c$

(*ii*) (*c*) Here, $i_c = 30°$

As $$n = \frac{c}{v} = \frac{1}{\sin i_c}$$

$$v = c \sin i_c = 3\times10^8 \times \sin 30°$$

$$v = 3 \times 10^8 \times 0.5$$

$$\therefore \quad v = 1.5\times10^8 \text{m/s}$$

(*iii*) (*c*) Dispersive power of prism depends upon nature of material of prism.

(*iv*) (*b*) We know that,

$$\delta = (n-1)A \text{ and } \delta = i - r$$

$$\delta = (1.5-1)30 = 0.5\times30 = 15°$$

Also, $$\delta = i - r = \theta - r$$

$$15° = \theta - 30° \qquad [\because \angle r = 30°]$$

$$\therefore \quad \theta = 15° + 30° = 45°$$

$$\therefore \quad \theta = i = 45°$$

OR

(*a*) $$n = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\frac{A}{2}} \text{ But } \frac{A+\delta_m}{2} = i = 45°$$

$$\sqrt{2} = \frac{\sin 45°}{\sin\frac{A}{2}} \Rightarrow \sin\frac{A}{2} = \frac{1}{2} \Rightarrow \frac{A}{2} = 30° \Rightarrow A = 60°$$

5. (*i*) (*b*) As from lens make's formula,

$$\frac{1}{f} \propto (n-1) \text{ and } P = \frac{1}{f} \qquad \Rightarrow \qquad P \propto (n-1)$$

Also, $$n \propto \frac{1}{\lambda}, \text{ Hence, } P \propto \frac{1}{\lambda}$$

Thus, if wavelength (λ) of light increases then power of lens decreases.

(*ii*) (*b*) From Lens maker's formula, $\frac{1}{f} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$

$$\Rightarrow \quad \frac{1}{f} = (n-1)\left(\frac{2}{f}\right) \qquad (\because f = R)$$

$$\Rightarrow \quad \frac{1}{2} = (n-1)$$

$$\therefore \quad n = 1.5$$

(*iii*) (*d*) When the refractive index of the object is same as that of the media around it, then the rays pass undeflected and the object appears to be invisible.

(*iv*) (*a*) For virtual and erect image,

$$m = \frac{v}{u} \Rightarrow 3 = \frac{v}{u} \Rightarrow v = 3u,$$

and $$f = \frac{1}{P} = f = \frac{1}{5} = 0.2 \text{ m} = 20 \text{ cm}$$

Using lens formula, $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

$$\frac{1}{20} = \frac{1}{3u} - \frac{1}{u} \qquad \Rightarrow \qquad \frac{1-3}{3u} = \frac{1}{20}$$

$$\Rightarrow \qquad u = -\frac{40}{3} \text{ cm}$$

And $$v = 3u = -3 \times \frac{40}{3} = -40 \text{ cm}$$

OR

(*d*) Using lens maker's formula, $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

$$\frac{1}{20} = (1.5 - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad ...(i)$$

And, $$\frac{1}{f_w} = \left(\frac{1.5}{\frac{4}{3}} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad ...(ii)$$

From equation (*i*) and (*ii*), we get,

$$\frac{\frac{1}{20}}{\frac{1}{f_w}} = \frac{0.5}{\frac{1}{8}} = 4 \quad \Rightarrow \quad \frac{f_w}{20} = 4 \quad \Rightarrow \quad f_w = 80 \text{ cm}$$

CONCEPTUAL QUESTIONS

Q. 1. When light travels from an optically denser medium to a rarer medium, why does the critical angle of incidence depend on the colour of light? **[*CBSE Ajmer 2015*]**

Ans. The refractive index is different for different colour wavelength as $n = a + \frac{b}{\lambda^2}$. Hence, critical angle $\sin i_c = \frac{1}{n}$ would also be different for different colour of light.

Q. 2. How does the angle of minimum deviation of a glass prism vary if the incident violet light is replaced by red light? **[*CBSE 2019 (55/3/1)*]**

Ans. The angle of minimum deviation decreases, if violet light is replaced by red light *i.e.*, $\delta_r < \delta_v$.

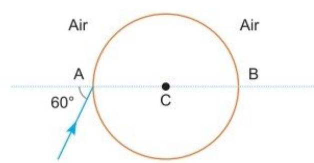
Q. 3. A ray of light falls on a transparent sphere with centre *C* as shown in the figure. The ray emerges from the sphere parallel to the line *AB*. Find the angle of refraction at *A* if refractive index of the material of the sphere is $\sqrt{3}$. **[*CBSE (F) 2014*]**

Ans. Refractive index, $n = \frac{\sin i}{\sin r}$

$$\sqrt{3} = \frac{\sin 60°}{\sin r}$$

$$\sin r = \frac{\sqrt{3}}{2} \times \frac{1}{\sqrt{3}} = \frac{1}{2}$$

$$\sin r = \sin 30° \Rightarrow r = 30°$$



Angle of refraction = **30°**.

Q. 4. For the same angle of incidence, the angle of refraction in two media A and B are 25° and 35° respectively. In which one of the two media is the speed of light lesser? **[*CBSE Bhubaneshwar 2015*]**

Ans. By snell's Law, $n = \frac{\sin i}{\sin r} = \frac{v_1}{v_2}$

$$\frac{n_A}{n_B} = \frac{\sin i/\sin r_A}{\sin i/\sin r_B} = \frac{\sin r_B}{\sin r_A} = \frac{v_1/v_A}{v_1/v_B}$$

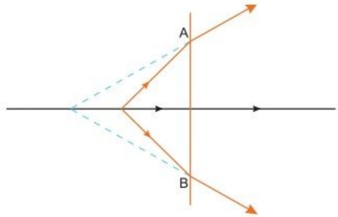
$$\frac{\sin r_B}{\sin r_A} = \frac{v_B}{v_A}$$

$$r_A < r_B \qquad \sin r_A < \sin r_B \quad \Rightarrow \quad v_A < v_B$$

Speed of light in A is lesser.

Q. 5. The line AB in the ray diagram represents a lens. State whether the lens is convex or concave.

[*CBSE Chennai 2015*]



Ans. It is a concave or diverging lens.

Reason: The refracted ray is bending away from the principal axis.

Q. 6. An object is placed in front of a converging lens. Obtain the conditions under which the magnification produced by the lens is (*i*) negative and (*ii*) positive.

[*CBSE 2022 (55/3/1), (55/3/3), Term-2*]

Ans. An object is placed in front of a converging lens.

(*i*) If, m = –ve, then real and inverted image is formed. Hence object should placed beyond F.

(*ii*) If, m = +ve, then virtual and erect image is formed. Hence object should placed between F and O.

Q. 7. A concave lens of refractive index 1.5 is immersed in a medium of refractive index 1.65. What is the nature of the lens? [*CBSE Delhi 2015*]

Ans. Concave lens, in medium of high refractive index, behaves as a convex lens (or a converging lens).

Reason: $$\frac{1}{f_m} = \left(\frac{n_g}{n_m} - 1\right)\left(-\frac{1}{R} - \frac{1}{R}\right)$$

Since $$n_m > n_g$$

$$\frac{1}{f_m} = +\text{ ve}$$

So, $f_m > 0$. Hence acts a convex lens.

Q. 8. What is the focal length of a combination of a convex lens of focal length 30 cm and a concave lens of focal length 20 cm in contact? Is the system a converging or a diverging lens? Ignore thickness of lenses. [*NCERT*]

Ans. Given $f_1 = +30$ cm, $f_2 = -20$ cm

The focal length (F) of combination of given by

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$\Rightarrow \qquad F = \frac{f_1 f_2}{f_1 + f_2} = \frac{30 \times (-20)}{30 - 20} = \mathbf{-60\ cm}$$

That is, the focal length of combination is 60 cm and it acts like a diverging lens.

Q. 9. A ray of light passes through an equilateral glass prism such that the angle of incidence is equal to angle of emergence and each of these angles is equal to $\frac{3}{4}$th of angle of prism. What is the value of angle of deviation? [*CBSE Patna 2015*]

Ans. In prism $i + e = A + D =$ and $i = e = \frac{3}{4}A$ (given)

So, $$A + D = \frac{3}{4}A + \frac{3}{4}A$$

$\Rightarrow$ $$D = \frac{3A}{2} - A = \frac{A}{2}$$

Since $A = 60°$ (being an equilateral glass prism)

So, $$D = \frac{60°}{2} = \mathbf{30°}$$

Q. 10. An astronomical telescope may be a refracting type or a reflecting type. Which of the two produces image of better quality? Justify your answer. ***[CBSE 2020 (55/4/1)]***

Ans. Reflecting telescope is preferred over refracting telescope because:

(*a*) No chromatic aberration, because mirror is used.

(*b*) Spherical aberration can be removed by using a parabolic mirror.

(*c*) Image is bright because no loss of energy due to reflection.

(*d*) Large mirror can provide easier mechanical support.

Q. 11. You are given following three lenses. Which two lenses will you use as an eyepiece and as an objective to construct an astronomical telescope? Give reason.

Lenses	Power (D)	Aperture (cm)
L_1	3	8
L_2	6	1
L_3	10	1

[CBSE Delhi 2009, CBSE (AI) 2017]

Ans. Objective : Lens L_1

Eyepiece : Lens L_3

Reason: The objective lens should have large aperture (here, 8 cm) and large focal length $\left(f = \frac{1}{\text{Power}}\right)$ while the eyepiece should have small aperture and small focal length.

Q. 12. Does the magnifying power of a microscope depend on the colour of the light used? Justify your answer. ***[CBSE (F) 2017]***

Ans. Yes, since magnification depends upon focal length and focal length depends on the colour and different colours have different wavelengths (*i.e.*, different refractive indices).

$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \qquad \text{(By Lens Maker's Formula)}$$

Also, magnification of compound microscope

$$M = \frac{-L}{f_0}\left(1 + \frac{D}{f_e}\right)$$

Q. 13. **(*a*) Explain briefly how the focal length of a convex lens changes with increase in wavelength of incident light.**

(*b*) What happens to the focal length of convex lens when it is immersed in water? Refractive index of the material of lens is greater than that of water. ***[HOTS] [CBSE (South) 2016]***

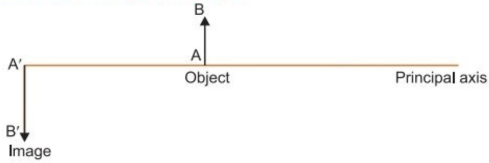
Ans. (*a*) Focal length increases with increase of wavelength.

$\frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\frac{2}{R}$ as wavelength increases, $\frac{n_2}{n_1}$ decreases hence focal length increases.

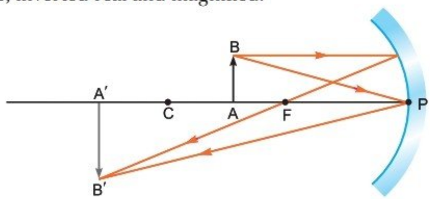
(*b*) As $n_2 > n_1$, $\left(\frac{n_2}{n_1} - 1\right)$ decreases so, focal length increases.

$$\frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\frac{2}{R}$$

Q. 14. Redraw the diagram given below and mark the position of the centre of curvature of the spherical mirror used in the given set up. *[CBSE Sample Paper]*



Ans. If the object is in between focus '*F*' and centre of curvature '*C*', image would be beyond the centre of curvature, inverted real and magnified.



Q. 15. A concave mirror and a converging lens have the same focal length in air. Which one of the two will have greater focal length when both are immersed in water? *[HOTS]*

Ans. Converging lens; the focal length of a spherical mirror remains unaffected.

For converging lens, $\frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_2} + \frac{1}{R_2}\right)$

When it is immersed in water

$$n_2 \text{ (in water)} < n_2 \text{ (in air)}$$

$\left(\frac{n_2}{n_1} - 1\right)$ decreases hence focal length of converging lens increases in water.

Q. 16. A concave lens is placed in water. Will there be any change in focal length? Give reason. *[HOTS]*

Ans. Focal length of lens in water $f_w = \dfrac{n_g - 1}{\frac{n_g}{n_w} - 1} f_a$

$As\, n_g > n_w, \frac{n_g}{n_w} > 1, \text{ so } f_w > f_a$

That is, focal length of lens in water will increase, but the nature of lens will remain unchanged.

Q. 17. For which colour the magnifying power of a simple microscope is highest? For which colour it is lowest?

Ans. It is highest for violet and lowest for red colour since $M = 1 + \frac{D}{f}$ and $f_V < f_R$

Q. 18. A telescope has been adjusted for relaxed eye. You are asked to adjust it for least distance of distinct vision, then how will you change the distance between two lenses? *[HOTS]*

Ans. For relaxed eye, $L = f_0 + f_e$

For least distance of distinct vision

$$L' = f_0 + u_e\,,\, u_e < f_e$$

Therefore, $L' < L$, that is, the distance will be decreased.

Q. 19. Will the focal length of a lens for red light be more, same or less than that for blue light? *[HOTS] [NCERT Exemplar]*

Ans. As the refractive index for red is less than that for blue $\frac{1}{f} \propto n - 1$, parallel beams of light incident on a lens will be bent more towards the axis for blue light compared to red. Thus the focal length for red light will be more than that for blue.

Q. 20. State the condition under which a large magnification can be achieved in an astronomical telescope. *[CBSE 2019 (55/3/1)]*

Ans. $F_O >> F_e$

Focal length of objective must be much greater than focal length of eyepiece **1**

[CBSE Marking Scheme 2019 (55/3/1)]

Q. 21. An unsymmetrical double convex thin lens forms the image of a point object on its axis. Will the position of the image change if the lens is reversed? *[HOTS] [NCERT Exemplar]*

Ans. No, the reversibility of the lens makes equation.

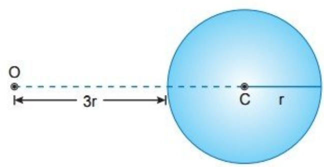
For convex lens, $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}=(n-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)=-(n-1)\left(\frac{1}{R_2}-\frac{1}{R_1}\right)$

On reversing the lens, values of R_1 and R_2 are reversed and so their signs. Hence, for a given position of object (u), position of image (v) remains unaffected.

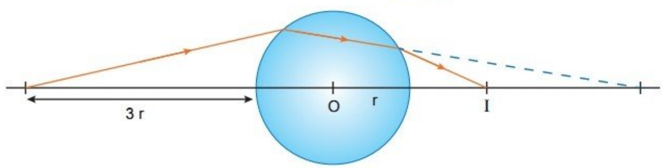
Very Short Answer Questions

Each of the following questions are of 2 marks.

Q. 1. A point object is placed at O in front of a glass sphere as shown in figure.
Show the formation of image by the sphere. *[CBSE 2022 (55/3/1), (55/3/3), Term-2]*



Ans.



Q. 2. For paraxial rays, show that the focal length of a spherical mirror is one-half of its radius of curvature. *[CBSE 2019 (55/3/1)]*

Ans. According to the law of reflection,

Angle of incidence (i) = Angle of reflection (r)

$\therefore \quad \angle ABC = \angle FBC$

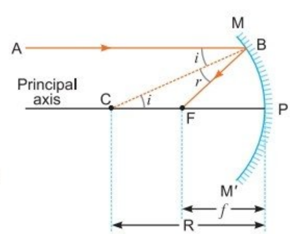
But $\quad \angle ABC = \angle BCF \quad$ (alternate angles)

$\therefore \quad \angle FBC = \angle BCF$

Triangle BCF is isosceles. Hence, $CF = FB \quad ...(i)$

If aperture of mirror is small, then point B is very near to P, so

$\therefore \quad FB = FP \quad ...(ii)$



From equations (i) and (ii), $CF = FP$

$$\therefore \qquad FP = \frac{FP + CF}{2} = \frac{PC}{2}$$

or
$$f = \frac{R}{2}$$

Thus, the focal length of a spherical mirror (concave mirror) is half of its radius of curvature.

Q. 3. The focal length of and equiconcave lens is $\frac{3}{4}$ times of radius of curvature of its surfaces. Find the refractive index of the material of the lens. Under what condition will this lens behave as a converging lens? [*CBSE 2020 (55/2/2)*]

Ans. Using lens maker's formula,

$$\frac{1}{f} = (\mu-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \qquad \frac{1}{2}$$

Given, $f = \frac{3}{4} R$, $R_1 = -R$, $R_2 = R$

$$\Rightarrow \quad -\frac{4}{3} = (\mu - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \qquad \frac{1}{2}$$

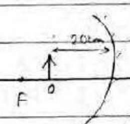
$$\Rightarrow \quad \mu = 1 + \frac{2}{3} = \frac{5}{3} \qquad \frac{1}{2}$$

If the lens is immersed in a medium of refractive index greater than 5/3, it will behave like a converging lens. ½

[*CBSE Marking Scheme 2020 (55/2/2)*]

Q. 4. An object is kept 20 cm in front of a concave mirror of radius of curvature 60 cm. Find the nature and position of the image formed. [*CBSE 2020 (55/2/1)*]

Ans.



Here, radius of curvature, $R = 60$ cm

$\therefore$ focal length, $|f| = 30$ cm. $\frac{1}{2}$

$\because \frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ here, $u = -20$ cm, $f = -30$ cm $\frac{1}{2}$

$-\frac{1}{20} + \frac{1}{v} = -\frac{1}{30} \Rightarrow \frac{1}{v} = \frac{1}{20} - \frac{1}{30} = \frac{1}{60}$

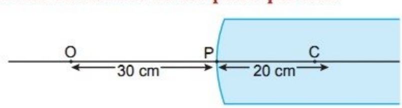
$\Rightarrow v = 60$ cm. $\frac{1}{2}$

$\therefore$ magnification, $m = -v/u = \frac{-60}{-20} = 3$.

$\therefore$ the image formed is virtual, erect and magnified in nature $\frac{1}{2}$

[*Topper's Answer 2020*]

Q. 5. A spherical convex surface of radius of curvature 20 cm, made of glass (n = 1.5) is placed in air. Find the position of the image formed, if a point object is placed at 30 cm in front of the convex surface on the principal axis. [*CBSE Sample Paper 2018*]



Ans. Here, $R = +20$ cm, $n_1 = 1.0$, $n_2 = 1.5$, $u = -30$ cm

Using, $\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$

$$\frac{1.5}{v} - \frac{1.0}{-30} = \frac{1.5 - 1.0}{20}$$

$$\Rightarrow \quad \frac{1.5}{v} + \frac{1}{30} = \frac{0.5}{20} = \frac{1}{40}$$

$$\Rightarrow \quad \frac{1.5}{v} = \frac{1}{40} - \frac{1}{30} = \frac{3-4}{120}$$

$$\Rightarrow \quad \frac{1.5}{v} = \frac{-1}{120}$$

$$\therefore \quad v = \mathbf{-180.0\ cm}$$

Q. 6. An angular magnification of 30X is desired using an objective of focal length 1.25 cm and an eye piece of focal length 5 cm. How will you set up the compound microscope for the final image formed at least distance of distinct vision? [*CBSE Sample Paper-2022, Term-2*]

Ans. $m_o = 30$, $f_o = 1.25$ cm, $f_e = 5$ cm

when image is formed at least distance of distinct vision,

$$D = 25 \text{ cm}$$

Angular magnification of eyepiece

$$m_e = \left(1 + \frac{D}{f_e}\right) = 1 + \frac{25}{5} = 6$$

Total angular magnification, $m = m_o m_e$

$$\Rightarrow \quad m_o = \frac{m}{m_e} = \frac{30}{6} = 5$$

As the objective lens forms the real image,

$$m_o = \frac{v_o}{u_o} = -5 \quad \Rightarrow \quad v_o = -5u_o$$

Using lens equation, $u_o = -1.5$ cm, $v_o = -5 \times (-1.5)$cm $= +7.5$ cm

Given $v_e = -D = -25$ cm, $f_e = +5$ cm, $u_e = ?$

Using again lens equation, $u_e = \frac{25}{6} = 4.17$ cm

Thus, object is to be placed at 1.5 cm from the objective and separation between the two lenses should be

$$L = v_o + |u_e| = \mathbf{11.67\ cm}$$

Q. 7. A small telescope has an objective lens of focal length 140 cm and an eyepiece of focal length 5.0 cm. Find the magnifying power of the telescope for viewing distant objects when

(*i*) the telescope is in normal adjustment, [*CBSE Sample Paper-2022, Term-2*]

(*ii*) the final image is formed at the least distance of distinct vision.

Ans. (*i*) In normal adjustment;

Magnifying power,

$$m = \frac{f_o}{f_e} = \left(\frac{140}{5}\right) = \mathbf{28}$$

(*ii*) When the final image is formed at the least distance of distinct vision (25 cm):

$$m = \frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right) = (28 \times 1.2) = \mathbf{33.6}$$

Q. 8. Calculate the radius of curvature of an equi-concave lens of refractive index 1.5, when it is kept in a medium of refractive index 1.4, to have a power of –5D? [*CBSE 2019 (55/1/1)*]

Ans. We know that

$$P = \frac{1}{f} = \left(\frac{n_2 - n_1}{n_1}\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

According to question $P = -5$ D,

$$n_2 = 1.5, n_1 = 1.4$$

Also, lens is equiconcave $R_1 = -R, R_2 = R$

Now, $$-5 = \left(\frac{1.5-1.4}{1.4}\right)\left(-\frac{1}{R} - \frac{1}{R}\right)$$

$\Rightarrow$ $$-5 = -\frac{0.1}{1.4} \times \frac{2}{R} \quad \Rightarrow \quad 5 = \frac{1}{14} \times \frac{2}{R}$$

$$\Rightarrow \frac{1}{R} = 35 \Rightarrow R = \frac{1}{35}\text{ m} = \frac{100}{35}\text{ cm} = \frac{20}{7}\text{ cm} = \mathbf{2.86\ cm}$$

Q. 9. Write two characteristics of image formed when an object is placed between the optical centre and focus of a thin convex lens. Draw the graph showing variation of image distance v with object distance u in this case. **[*CBSE Sample Paper 2021*]**

Ans. Characteristics of the images formed:

(*i*) Virtual and enlarged image

(*ii*) Same side of the object

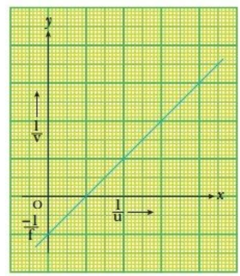
We know that,

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

As both image and object lie on the same side, both v and u are negative,

$$\frac{-1}{v} + \frac{1}{u} = \frac{1}{f} \quad \text{or} \quad \frac{1}{v} = \frac{-1}{f} + \frac{1}{u} = \frac{1}{u} - \frac{1}{f}.$$

Comparing with $y = mx + c$, the graph is shown.



Q. 10. An astronomical telescope has an angular magnification of magnitude 5 for distant objects. The separation between the objective and an eye piece is 36 cm and the final image is formed at infinity. Calculate the focal length of the objective and the focal length of the eye piece? **[*CBSE Sample Paper 2018*]**

Ans. Magnification $m = f_0/f_e = 5$

$$f_0 = 5f_e$$

Now, length of the tube, $L = f_0 + f_e$

$$36 = 5f_e + f_e$$
$$6f_e = 36 \text{ cm}$$
$$f_e = \mathbf{6\ cm}$$

$\therefore$ $$f_0 = 5 \times 6 = \mathbf{30\ cm}$$

Q. 11. The focal lengths of the objective and the eye-piece of a compound microscope are 1.0 cm and 2.5 cm respectively. Find the tube length of the microscope for obtaining a magnification of 300. **[*CBSE 2023 (55/2/1)*]**

Ans. Here, $f_0 = 1.0$ cm, $f_e = 2.5$ cm, $m = 300$, $D = 25$ cm,

Magnifying power,

$$|m| = \frac{L}{f_0} \cdot \frac{D}{f_e} \text{ (when image at infinity)}$$

$$\Rightarrow \qquad 300 = \frac{L}{1.0} \cdot \frac{25}{2.5}$$

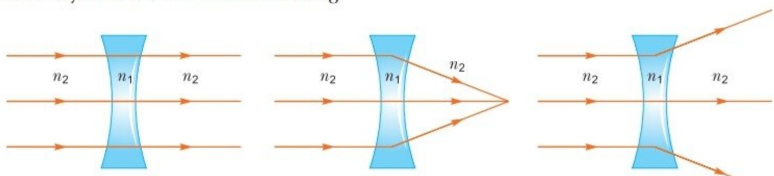
$$\therefore \qquad L = \mathbf{30\ cm}$$

Q. 12. The refractive index of a material of a concave lens is n_1. It is immersed in a medium of refractive index n_2. A parallel beam of light is incident on the lens. Trace the path of emergent rays when (*i*) $n_2 = n_1$ (*ii*) $n_2 > n_1$ (*iii*) $n_2 < n_1$.

Ans. From lens maker's formula, $\frac{1}{f} = \left(\frac{n_1}{n_2} - 1\right)\left(-\frac{1}{R_2} - \frac{1}{R_2}\right)$

(*i*) for $n_1 = n_2 \Rightarrow f = \infty$ (*ii*) for $n_1 < n_2 \Rightarrow f > 0$ (*iii*) for $n_1 > n_2 \Rightarrow f < 0$

The path of rays in three cases is shown in fig.



$n_2 = n_1$ (*i*) $n_2 > n_1$ (*ii*) $n_2 < n_1$ (*iii*)

Q. 13. A convex lens made of a material of refractive index n_1 is kept in a medium of refractive index n_2. Parallel rays of light are incident on the lens. Complete the path of rays of light emerging from the convex lens if: (*i*) $n_1 > n_2$ (*ii*) $n_1 = n_2$ (*iii*) $n_1 < n_2$.

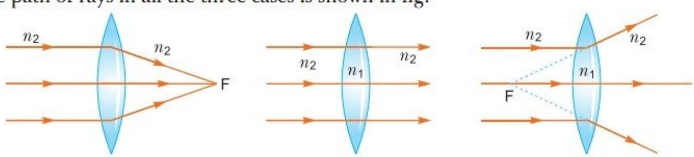
Ans. From lens maker's formula, $\frac{1}{f} = \left(\frac{n_1}{n_2} - 1\right)\left(\frac{1}{R_2} + \frac{1}{R_2}\right)$

In case (*i*) $n_1 > n_2$, the lens behaves as convergent lens.

In case (*ii*) $n_1 = n_2$, the lens behaves as a plane plate.

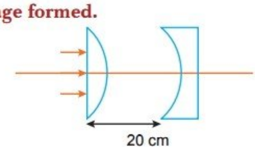
In case (*iii*) $n_1 < n_2$, the lens behaves as a divergent lens.

The path of rays in all the three cases is shown in fig.



(*i*) $n_1 > n_2$ (*ii*) $n_1 = n_2$ (*iii*) $n_1 < n_2$

Q. 14. In the given figure the radius of curvature of curved face in the plano convex and the plano-concave lens is 15 cm each. The refractive index of the material of the lenses is 1.5. Find the final position of the image formed. **[*CBSE 2023 (55/2/1)*]**



Ans. From lens maker's formula, $\frac{1}{f} = (1.5 - 1)\left(\frac{1}{\infty} - \frac{1}{(-15)}\right)$

we get, $\qquad f = 30$ cm

Again, $\qquad \frac{1}{f} = (1.5 - 1)\left(\frac{1}{(-15)} - \frac{1}{\infty}\right)$

We get, $f = -30$ cm

Using lens formula, $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

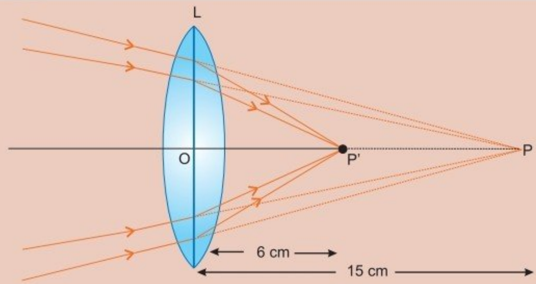
$\Rightarrow \quad -\frac{1}{30} = \frac{1}{v} - \frac{1}{10} \qquad (\because u = 10)$

$\Rightarrow \quad \frac{1}{v} = \frac{1}{10} - \frac{1}{30} = \frac{3-1}{30} = \frac{2}{30} = \frac{1}{15}$

$\therefore \quad v = \mathbf{15\ cm}$

Q. 15. A beam of light converges at a point P. Now a convex lens is placed in the path of the convergent beam at 15 cm from P. At what point does a beam converge if the convex lens has a focal length 10 cm? *[CBSE 2019 (55/4/1)]*

Ans.



½

Using lens formula,

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$ ½

Here $u = +15$ cm; $f = +10$ cm ½

$\Rightarrow \quad \frac{1}{v} - \frac{1}{f} + \frac{1}{u} = \frac{1}{10} + \frac{1}{15}$

$\therefore \quad v = 6$ cm ½

[CBSE Marking Scheme 2019 (55/4/1)]

Q. 16. A small pin fixed on a table top is viewed from above from a distance of 50 cm. By what distance the pin appear to be raised if it is viewed from the same point through a 15 cm thick glass slab held parallel to the table? Refractive index of glass = 1.5. Does the answer depend on the location of the slab? *[NCERT]*

Ans. Apparent thickness of slab $= \frac{\text{Real thickness}}{\text{Refractive index}} = \frac{H}{n}$

Displacement of pin, $x = \left(H - \frac{H}{n}\right) = H\left(1 - \frac{1}{n}\right)$

Here, $H = 15\text{ cm}, n = 1.5,$

$\therefore \quad x = H\left(1 - \frac{1}{n}\right) = 15\left(\frac{1.5-1}{1.5}\right)\text{cm} = \mathbf{5\ cm}$

Thus the pin appears to be raised by 5 cm.

The answer does not depend upon the location of slab.

Q. 17. (*i*) State the condition under which a large magnification can be achieved in an astronomical telescope. *[CBSE 2019 (55/3/1)]*

(*ii*) Give two reasons to explain why a reflecting telescope is preferred over a refracting telescope. *[CBSE (F) 2017]*

Ans. (i) (a) When final image is formed at least distance of distinct vision, magnification

$$m = \frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right)$$

(b) Magnification in normal adjustment,

$$m = \frac{f_o}{f_e}$$

Clearly, for large magnification

$$f_o >> f_e$$

(ii) Reflecting telescope is preferred over refracting telescope because

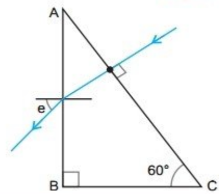
(a) No chromatic aberration, because mirror is used.

(b) Spherical aberration can be removed by using a parabolic mirror.

(c) Image is bright because no loss of energy due to reflection.

(d) Large mirror can provide easier mechanical support. *(any two)*

Q. 18. Calculate the angle of emergence (e) of the ray of light incident normally on the face AC of a glass prism ABC of refractive index $\sqrt{3}$. How will the angle of emergence change qualitatively, if the ray of light emerges from the prism into a liquid of refractive index 1.3 instead of air? [*CBSE 2020 (55/5/1)*]



Ans. Applying Snell's law at face AB, we get

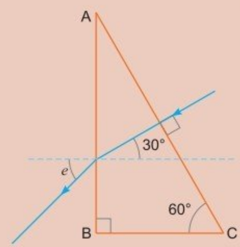
$\Rightarrow \sqrt{3}\sin 30 = 1.\sin e$ ½

$\Rightarrow \sqrt{3} \times \frac{1}{2} = \sin e$ ½

$\Rightarrow \frac{\sqrt{3}}{2} = \sin e$

$\Rightarrow \sin 60 = \sin e$

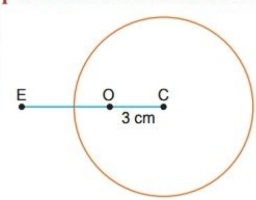
$\therefore e = 60°$ ½



When the medium (the air) in which prism is kept is replaced with a liquid of refractive index 1.3 the angle of emergence would derease. It is because bending in the ray of light will be lesser. ½

[*CBSE Making Scheme 2020 (55/5/1)*]

Q. 19. A solid glass sphere of radius 6.0 em has a small air bubble trapped at a distance 3.0 cm from its center C as shown in the figure. The refractive index of the material of the sphere is 1.5. Find the apparent position of this bubble when seen through the surface of the sphere from an outside point E in air. [*CBSE 2023 (55/1/1/)*]



Ans. Here, $R = 6$ cm, $u = 6 - 3 = 3$ cm, $n_1 = 1.5$. $n_2 = 1$

From the relation, $\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$

$$\frac{1}{v} - \frac{1.5}{3} = \frac{1-1.5}{-6}$$

$$\frac{1}{v} = \frac{0.5}{6} + \frac{1.5}{3} = \frac{0.5-3}{6} = -\frac{2.5}{6}$$

$$\therefore \qquad v = -\frac{6}{2.5} = \mathbf{2.4\ cm}$$

Q. 20. An equilateral glass prism has a refractive index 1.6 in air. Calculate the angle of minimum deviation of the prism, when kept in a medium of refractive index $4\sqrt{2}/5$.

[*CBSE 2019 (55/1/2)*]

Ans.

Refractive index of prism $= 1.6 = \frac{8}{5} - n_1$

Refractive index of surrounding medium $= \frac{4\sqrt{2}}{5} - n_2$

Refractive index of prism w.r.t surroundings $= n_{12} = \frac{n_1}{n_2}$

$$\mu = \frac{8^2 \cancel{5}}{\cancel{8}\ \cancel{4}\sqrt{2}} = \sqrt{2}$$

So, using the relation,

$$\mu = \frac{\sin\left(\frac{A + \delta_{min}}{2}\right)}{\sin \frac{A}{2}}$$

A = angle of prism = 60°, δ_{min} = angle of minimum deviation

we get,

$$\sqrt{2} = \frac{\sin\left(\frac{60 + \delta_{min}}{2}\right)}{\sin 30°}$$

$$\frac{1}{\sqrt{2}} = \sin\left(\frac{60 + \delta_{min}}{2}\right)$$

$$\frac{60 + \delta_{min}}{2} = \sin^{-1}\frac{1}{\sqrt{2}} = 45°$$

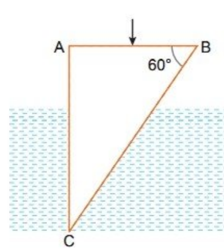
$$60° + \delta_{min} = 90°$$

$$\delta_{min} = 30°$$

Hence, angle of minimum deviation of prism = 30°

[*Topper's Answer 2019*]

Q. 21. (*a*) A ray of light is incident normally on the face *AB* of a right-angled glass prism of refractive index $_an_g = 1.5$. The prism is partly immersed in a liquid of unknown refractive index. Find the value of refractive index of the liquid so that the ray grazes along the face *BC* after refraction through the prism.



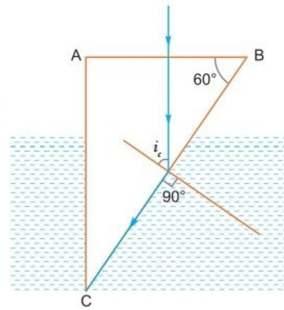
(*b*) Trace the path of the rays if it were incident normally on the face *AC*. **[*CBSE Ajmer 2015*]**

Ans. (*a*) From Snell's law,

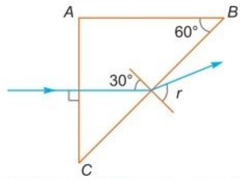
$$_an_g \sin i_c = {_an_l} \sin 90°$$

$$1.5 \times \sin 60^\circ = {}_a n_l$$

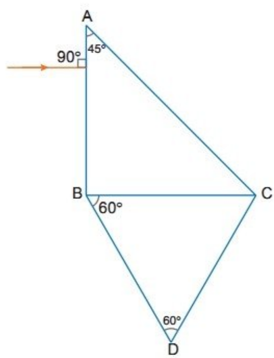
$$\therefore \qquad {}_a n_l = 1.5 \times \frac{\sqrt{3}}{2} = \mathbf{1.3}$$



(*b*) The ray strikes at an angle of $30^\circ < i_c$. So, the ray of light deviates apart from the normal, as it moves from denser to rarer medium.



Q. 22. Two prisms *ABC* and *DBC* are arranged as shown in figure.

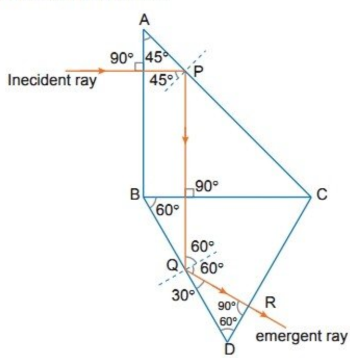


The critical angles for the two prisms with respect to air are 41.1° and 45° respectively. Trace the path of the ray through the combination. **[*CBSE 2022 (55/3/1), Term-2*]**

Ans. For surface *AC* : at point *P*, $i > i_c$ (*i.e.*, $i_{c_1} = 41.1^\circ$); hence ray will suffer total internal reflection.

For surface *BD* : at point *Q*; again $i > i_c$ (*i.e.*, $i_{c_2} = 45^\circ$); hence ray will suffer total internal reflection.

For surface *DC* : ray will be normal to *DC*.



Q. 23. A ray of light passing from air through an equilateral glass prism undergoes minimum deviation when the angle of incidence is $\frac{3}{4}$th of the angle of prism. Calculate the speed of light in the prism. *[CBSE (AI) 2017]*

Ans. Angle of prism, $A = 60°$ (Since prism is an equilateral glass prism)

We are given that

$$i = \frac{3}{4}A = \frac{3}{4}\times 60°$$

$$\therefore \quad i = 45°$$

At minimum deviation,

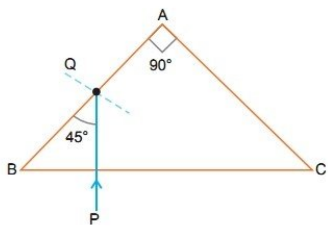
$$r = \frac{A}{2} = 30°$$

$$\therefore \quad n = \frac{\sin i}{\sin r} = \frac{\sin 45°}{\sin 30°} = \frac{\frac{1}{\sqrt{2}}}{\frac{1}{2}} = \frac{2}{\sqrt{2}} = \sqrt{2}$$

$\therefore$ Speed of light in the prism is given by

$$v = \frac{c}{n} = \frac{3\times 10^8}{\sqrt{2}} = \mathbf{2.1\times 10^8\ m/s}$$

Q. 24. A ray of light PQ enters an isosceles right angled prism ABC of refractive index 1.5 as shown in figure. *[CBSE 2020 (55/4/1)]*



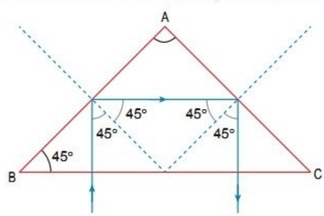
(*i*) Trace the path of the ray through the prism.

(*ii*) What will be the effect on the path of the ray if the refractive index of the prism is 1.4?

Ans. (*i*) $n = 1.5$

$$i_c = \sin^{-1}\left(\frac{1}{\mu}\right)$$

$$= \sin^{-1}\left(\frac{2}{3}\right) = \sin^{-1}(0.66) = 41°$$



Here, $i = 45°$

Since $i > i_c$

Hence the ray will suffer total interval reflection

(*ii*) If $n = 1.4$

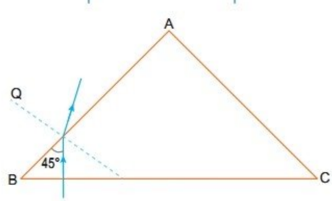
$$i_c = \sin^{-1}\left(\frac{1}{1.4}\right)$$

$$= 45.58°$$

Here $i = 45°$

Since $i < i_c$

Hence the ray will get refracted.



Short Answer Questions

Each of the following questions are of 3 marks.

Q. 1. (*i*) What is total internal reflection? Under what conditions does it occur?

[CBSE 2022 (55/2/1), Term–2]

(*ii*) Find a relation between critical angle and refractive index.

(*iii*) Name one phenomenon which is based on total internal reflection.

[CBSE (East) 2016, 2019 (55/1/1)]

Ans. (*i*) When a ray of light travels from an optically denser medium into a rarer medium at an angle greater than the critical angle, it reflects back into the denser medium. This phenomenon is called total internal reflection.

Conditions for total internal reflection:

(*a*) Light must travel from denser medium to rarer medium.

(*b*) Angle of incidence in denser medium must be greater than critical angle.

(*ii*) $\frac{1}{n} = \frac{\sin i}{\sin r}$, for total internal reflection to occur $i \geq i_c$; at critical angle, angle of refraction,

$r = 90°$ hence $\frac{1}{n} = \frac{\sin i_c}{\sin 90^o} \Rightarrow n = \frac{1}{\sin i_c}$

(*iii*) (*a*) Mirage (*b*) Optical fibre (*c*) Sparkling of diamond (*d*) Shinning of air bubbles in water (*e*) Totally reflecting prism. *(any one)*

Q. 2. (*i*) Name the phenomenon on which the working of an optical fibre is based.

[CBSE 2022 (55/1/1), Term–2]

(*ii*) What are the necessary conditions for this phenomenon to occur?

[CBSE 2022 (55/3/1), Term–2]

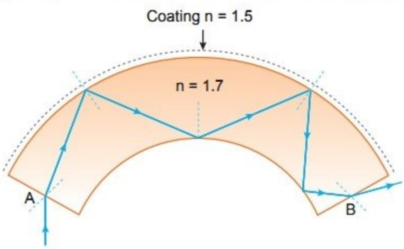
(*iii*) Draw a labelled diagram of an optical fibre and show how light propagates through the optical fibre using this phenomenon. *[CBSE 2019, CBSE 2022 (55/1/1), (55/2/3), Term–2]*

Ans. (*i*) Working of an optical fibre is based on total internal reflection.

(*ii*) (*a*) Rays of light have to travel from optically denser medium to optically rarer medium and

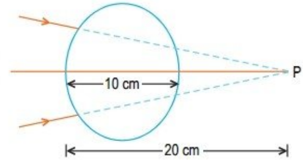
(*b*) Angle of incidence in the denser medium should be greater than critical angle.

(*iii*)



Q. 3. A converging beam of light travelling in air converges at a point *P* as shown in the figure. When a glass sphere of refractive index 1.5 is introduced in between the path of the beam, calculate the new position of the image. Also draw the ray diagram for the image formed.

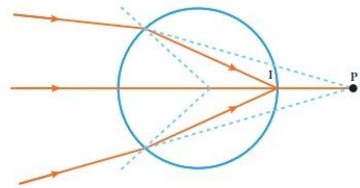
[CBSE 2019 (55/3/1)]



Ans. Given, $u = 20$ cm

$$n_1 = 1$$

$$R = \frac{10}{2} = 5 \text{ cm}$$



As the light passes from rare to denser medium, so

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$$

$$\frac{1.5}{v} - \frac{1}{20} = \frac{1.5 - 1}{5}$$

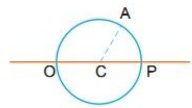
$$\frac{1.5}{v} = \frac{1}{10} + \frac{1}{20}$$

$$\frac{1.5}{v} = \frac{2+1}{20}$$

$$v = \mathbf{+10\ cm}$$

Thus, the image is formed at the other end (I) of the diameter.

Q. 4. A point 'O' marked on the surface of a glass sphere of diameter 20cm is viewed through glass from the position directly opposite to the point O. If the refractive index of the glass is 1.5, find the position of the image formed. Also, draw the ray diagram for the image formed. Also, draw the ray diagram for the formation of the image. ***[CBSE 2019 (55/3/1)]***



Ans. The mark O on the surface of glass sphere acts as object. The incident ray OA is in glass and refracted ray AB is in air. I is the image of O.

Thus, $n_1 = 1$, $n_2 = 1.5$

$u = -20$ cm (Minus sign is taken for refraction at concave surface)

As light passes from denser to rarer medium, so

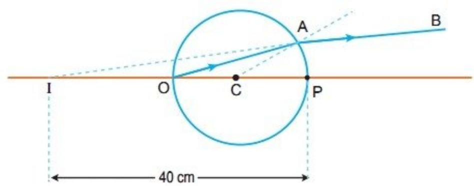
$$\frac{n_1}{v} - \frac{n_2}{u} = \frac{n_1 - n_2}{R}$$

$$\frac{1}{v} + \frac{1.5}{20} = \frac{1 - 1.5}{-10}$$

$$\frac{1}{v} = \frac{1}{20} - \frac{3}{40}$$

$$\frac{1}{v} = \frac{2-3}{40} = \frac{-1}{40}$$

$$v = \mathbf{-40\ cm}$$



Negative sign shows that the image is virtual. It is formed on the same side of the refracting surface as the object at a distance of 40 cm from the pole P.

Q. 5. Use the mirror equation to show that

(a) an object placed between f and $2f$ of a concave mirror produces a real image beyond $2f$. ***[CBSE Delhi 2015, (F) 2017, 2019 (55/3/3)]***

(b) a convex mirror always produces a virtual image independent of the location of the object.

(c) an object placed between the pole and focus of a concave mirror produces a virtual and enlarged image. ***[NCERT] [CBSE (AI) 2011]***

Ans. (a) Mirror equation is $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$ *or* $\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$

For a concave mirror, f is negative, *i.e.*, $f < 0$.

For a real object (on the left of mirror), $u < 0$

$\therefore \qquad 2f < u < f \text{ or } \frac{1}{2f} > \frac{1}{u} > \frac{1}{f}$

or $\qquad -\frac{1}{2f} < -\frac{1}{u} < -\frac{1}{f} \text{ or } \frac{1}{f} - \frac{1}{2f} < \frac{1}{f} - \frac{1}{u} < \frac{1}{f} - \frac{1}{f}$

or $\qquad \frac{1}{2f} < -\frac{1}{v} < 0 \quad i.e., \frac{1}{v}$ is negative.

This implies that v is negative.

Also from above inequality $2f > v$

or $\qquad |2f| < |v| \qquad (\because\ 2f$ and v are negative)

Hence, the real image is formed beyond $2f$.

(*b*) For a convex mirror, f is positive, *i.e.*, $f > 0$.

For a real object on the left, u is negative

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} \Rightarrow \frac{1}{v} = \frac{1}{f} - \frac{1}{u}$$

As u is negative and f is positive; $\frac{1}{v}$ must be positive, so v must be positive *i. e.* , image lies behind the mirror. Hence, image is virtual whatever the value of u may be.

(*c*) Using mirror formula, $\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$ ...(*i*)

For a concave mirror, f is negative *i.e.*, $f < 0$

As u is also negative, so $f < u < 0$

This implies, $\qquad \frac{1}{f} - \frac{1}{u} > 0$

Then from (*i*) $\frac{1}{v} > 0$ or v is positive.

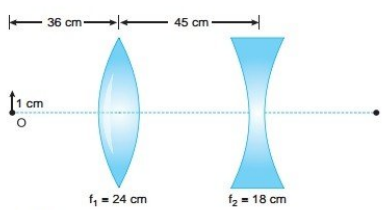
i.e., image is on the right and hence **virtual**.

Magnification, $m = -\frac{v}{u} = -\frac{f}{u-f}$

As u is negative and f is positive, magnification $m = \frac{|f|}{|f| - |u|} > 1$ *i.e.*, image is enlarged.

Q. 6. Two thin lenses L_1 and L_2, L_1 being a convex lens of focal length 24 cm and L_2 a concave lens of focal length 18 cm are placed coaxially at a separation of 45 cm. A 1 cm tall object is placed in front of the lens L_1 at a distance of 36 cm. Find the location and height of the image formed by the combination. **[*CBSE 2023 (55/4/1)*]**

Ans.



Here, $u_1 = -36$ cm, $f_1 = 24$

Image formed by first lens, L_1.

Using lens formula,

$$\frac{1}{f_1} = \frac{1}{v_1} - \frac{1}{u_1}$$

$$\Rightarrow \qquad \frac{1}{v_1} = \frac{1}{f_1} + \frac{1}{u_1} = \frac{1}{24} + \frac{1}{(-36)} = \frac{3-2}{72} = \frac{1}{72}$$

$\therefore \qquad v_1 = 72$ cm

Hence, Image formed by convex lens is real and inverted but it acts as virtual object for lens, L_2.

Now, $u_2 = 72 - 45 = 27$ cm

Again using lens formula,

$$\frac{1}{f_2} = \frac{1}{v_2} - \frac{1}{u_2}$$

$$\Rightarrow \qquad \frac{1}{v_2} = \frac{1}{f_2} + \frac{1}{u_2} = \frac{1}{(-18)} + \frac{1}{(27)}\text{s}$$

$$= \frac{-3+2}{54} = -\frac{1}{54}$$

$\therefore \qquad v_2 = \mathbf{-54\ cm}$

Hence, final image will form at 54 cm from the left side of concave lens.

Final distance, $v'_2 = -54 - (-45) = -9$ cm (to the left of convex lens)

So, magnification,

$$m = \frac{h_2}{h_1} = \frac{v'_2}{u}$$

$$\Rightarrow \qquad \frac{h_2}{1} = \frac{-9}{-36} = \frac{1}{4}$$

$$\therefore \qquad h_2 = \frac{1}{4}\text{ cm} = \mathbf{0.25\ cm.}$$

Q. 7. The image of a small electric bulb fixed on the wall of a room is to be obtained on the opposite wall 3 m away by means of a large convex lens. What is the maximum possible focal length of the lens required for the purpose? **[*NCERT*]**

Ans. For a fixed distance D between object and image for its real image

$$D = |u| + |v| \qquad \text{...}(i)$$

$$x = v - u \qquad \text{...}(ii)$$

From equation (*i*) and (*ii*),

$$v = \frac{D+x}{2} \qquad u = \frac{D-x}{2}$$

Sign convention: u is negative and v is positive.

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} = \frac{2}{D+x} + \frac{2}{D-x} = \frac{4D}{D^2 - x^2}$$

$$\Rightarrow \qquad f = \frac{D^2 - x^2}{4D}$$

where x is the separation between two positions of lens.

For maximum f, $x = 0$

$$\therefore \qquad f_{\max} = \frac{D}{4}$$

Given $D = 3$ m

$$f = \frac{3}{4}\text{ m} = \mathbf{0.75\ m}$$

Q. 8. A thin equiconvex lens of radius of curvature R made of material of refractive index μ_1 is kept coaxially, in contact with an equiconcave lens of the same radius of curvature and refractive index μ_2 ($>\mu_1$). Find: **[*CBSE 2022 (55/1/1), Term–2*]**

(*i*) the ratio of their powers, and

(*ii*) the power of the combination and its nature.

Ans. (*i*) From Lens maker's formula, $= \frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

$$P_1 = P_{Convex} = (\mu - 1)\left(\frac{1}{R_1} - (\frac{1}{R_2})\right) \qquad \text{½}$$

$$= (\mu - 1)\left(\frac{2}{R}\right)$$

$$P_2 = P_{Convex} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$= (\mu - 1)\left(\frac{2}{R}\right)$$ ½

$$\therefore \frac{P_1}{P_2} = \frac{(\mu_1 - 1)}{(\mu_2 - 1)} = \frac{(\mu_1 - 1)}{(1 - \mu_2)}$$ ½

(*ii*) For combination of lenses, $P = P_1 + P_2$

$$= (\mu_1 - 1)\left(\frac{2}{R}\right) + (-(\mu_2 - 1))\left(\frac{2}{R}\right)$$ ½

$$= \frac{2(\mu_1 - \mu_2)}{R}$$

As $\mu_2 > \mu_1$, P is negative ½

$\therefore$ Nature is diverging. ½

[*CBSE Making Scheme-2022 (55/1/1), Term–2*]

Q. 9. What are optical fibres? Mention their one practical application.

[*CBSE Delhi 2011, Guwahati 2015*]

Ans. Optical Fibre: An optical fibre is a device based on total internal reflection by which a light signal may be transmitted from one place to another with a negligible loss of energy. It is a very long and thin pipe of quartz ($n = 1.7$) of thickness nearly $\approx 10^{-4}$ m coated all around with a material of refractive index 1.5. A large number of such fibres held together form a *light pipe* and are used for communication of light signals. When a light ray is incident on one end at a small angle of incidence, it suffers refraction from air to quartz and strikes the quartz-coating interface at an angle more than the critical angle and so suffers total internal reflection and strikes the opposite face again at an angle greater than critical angle and so again suffers total internal reflection. Thus the ray within the fibre suffers multiple total internal reflections and finally strikes the other end at an angle less than critical angle for quartz-air interface and emerges in air.

As there is no loss of energy in total internal reflection, the light signal is transmitted by this device without any appreciable loss of energy.

Application : Optical fibre is used to transmit light signal to distant places.

For diagram, Refer to Question 2 (*iii*), Short Answer Question.

Q. 10. The focal length of a convex lens made of glass of refractive index (1.5) is 20 cm.

What will be its new focal length when placed in a medium of refractive index 1.25 ?

Is focal length positive or negative? What does it signify? **[*CBSE Sample Paper-2022, Term–2*]**

Ans. Given, ${}^a\mu_g = 1.5$

Focal length of the given convex lens when it is placed in air is

$$f = +20 \text{ cm}$$

Refractive index of the given medium with respect to air is

$${}^a\mu_m = 1.25$$

New focal length of the given convex lens when placed in a medium is f'

$$\frac{1}{f} = ({}^a\mu_g - 1)\left[\left(\frac{1}{R_1}\right) + \left(\frac{1}{R_2}\right)\right] \quad ...(i)$$

$$\frac{1}{f'} = ({}^m\mu_g - 1)\left[\left(\frac{1}{R_1}\right) + \left(\frac{1}{R_2}\right)\right] \quad ...(ii)$$

Dividing (*i*) by (*ii*), we get

$$\frac{f'}{f} = \frac{({}^{a}\mu_g - 1)}{({}^{m}\mu_g - 1)} = \frac{(1.5-1)}{(1.2-1)} = \frac{0.5}{0.2} = \frac{5}{2} = 2.5$$

$$f' = 2.5f = (2.5 \times 20)\text{ cm} = +50\text{ cm as } {}^{m}\mu_g = \frac{\mu_g}{\mu_m} = \frac{1.5}{1.25} = 1.2$$

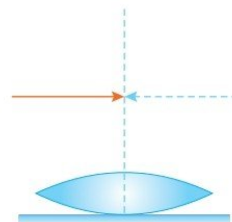
New focal length is positive.

The significance of the positive sign of the focal length is that given convex lens is still converging in the given medium.

Q. 11. A symmetric biconvex lens of radius of curvature *R* and made of glass of refractive index 1.5, is placed on a layer of liquid placed on top of a plane mirror as shown in the figure. An optical needle with its tip on the principal axis of the lens is moved along the axis until its real, inverted image coincides with the needle itself. The distance of the needle from the lens is measured to be *x*. On removing the liquid layer and repeating the experiment, the distance is found to be *y*. Obtain the expression for the refractive index of the liquid in terms of *x* and *y*. [*CBSE 2018*]

Ans. Let n_l denote the refractive index of the liquid. When the image of the needle coincides with the lens itself; its distance from the lens, equals the relevant focal length.

With liquid layer present, the given set up, is equivalent to a combination of the given (convex) lens and a concave plane/plano concave 'liquid lens'.



We have $$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

and $$\frac{1}{f} = \left(\frac{1}{f_1} + \frac{1}{f_2}\right)$$

As per the given data, we then have

$$\frac{1}{f_2} = \frac{1}{y} = (1.5-1)\left(\frac{1}{R} - \frac{1}{(-R)}\right) = \frac{1}{R}$$

$$\therefore \quad \frac{1}{x} = (n_l - 1)\left(-\frac{1}{R}\right) + \frac{1}{y} = \frac{-n_l}{y} + \frac{2}{y}$$

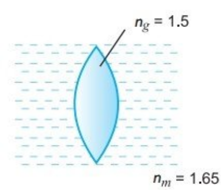
$$\therefore \quad \frac{n_l}{y} = \frac{2}{y} - \frac{1}{x} = \left(\frac{2x-y}{xy}\right)$$

or $$\boldsymbol{n_l = \left(\frac{2x-y}{x}\right)}$$

Q. 12. A biconvex lens of glass of refractive index 1.5 having focal length 20 cm is placed in a medium of refractive index 1.65. Find its focal length. What should be the value of the refractive index of the medium in which the lens should be placed so that it acts as a plane sheet of glass?

[*CBSE Bhubaneshwar 2015*]

Ans. From lens maker's formula, when lens in a medium



$$\frac{1}{f_m} = \left(\frac{n_g}{n_m} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad \ldots(i)$$

When lens in air $$\frac{1}{f_a} = (n_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad \ldots(ii)$$

From equation (*i*) and (*ii*), we get

$$\frac{f_a}{f_m} = \frac{\left(\frac{n_g}{n_m} - 1\right)}{(n_g - 1)}$$

$$\frac{20\text{ cm}}{f_m} = \frac{\left(\frac{1.5}{1.65} - 1\right)}{(1.5-1)}$$

$$\Rightarrow \qquad f_m = \frac{20 \times (1.5-1)}{\left(\frac{1.5}{1.65}-1\right)} = \frac{20 \times 0.5 \times 1.65}{-0.15} = \mathbf{-110\ cm}$$

If lens in the medium behave as a plane sheet of glass. Then $f_m = \infty$

$$\frac{1}{\infty} = \left(\frac{n_g}{n_m}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

$$\Rightarrow \left(\frac{n_g}{n_m}-1\right) = 0 \ \Rightarrow n_g = n_m = \mathbf{1.5}$$

The refractive index of the medium must be 1.5.

Q. 13. A point source in air is kept 24 cm in front of a concave spherical glass surface ($_a\mu_g$ = 1.5) and radius of curvature 60 cm. Find the nature of the image formed and its distance from the point source. ***[CBSE 2022 (55/1/1), Term–2]***

Ans. Relation for concave spherical surface,

$$\Rightarrow \qquad \frac{\mu_1}{-u} + \frac{\mu}{v} = \frac{\mu-1}{R} \qquad ½$$

$$\Rightarrow \qquad \frac{1}{-u} + \frac{\mu}{v} = \frac{\mu-1}{R} \qquad ½$$

$$\Rightarrow \qquad \frac{1}{-(-24)} + \frac{1.5}{v} = \frac{1.5-1}{-60} \qquad ½$$

$$\therefore \qquad v = -30 \text{ cm}$$

Distance of image from point source = –24 –(–30) = 60 cm ½

Nature of image = Virtual image 1

[CBSE Marking Scheme 2022 (55/1/1), Term–2]

Q. 14. A convex lens of focal length 20 cm and a concave lens of focal length 15 cm are kept 30cm apart with their principal axes coincident. When an object is placed 30 cm in front of the convex lens, calculate the position of the final image formed by the combination. Would this result change if the object were placed 30 cm in front of the concave lens? Give reason. ***[CBSE 2019 (55/5/1)]***

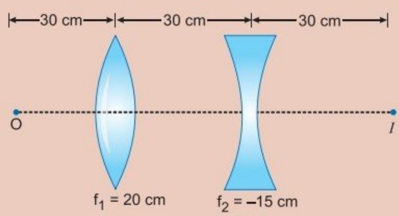
Ans. For Image formed by convex lens,

Using Lens Formula

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\Rightarrow \qquad \frac{1}{20} = \frac{1}{v} + \frac{1}{30}$$

$$\therefore \qquad v = \frac{20 \times 30}{30-20} = 60 \text{ cm}$$



½ 1

Again, for concave lens = + 30 cm

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\Rightarrow \qquad \frac{1}{-15} = \frac{1}{v} - \frac{1}{30}$$

$$\therefore \qquad v = \frac{15 \times 30}{15-30} = -30 \text{ cm} \qquad 1$$

No, the result will not change from principle of reversibility. ½

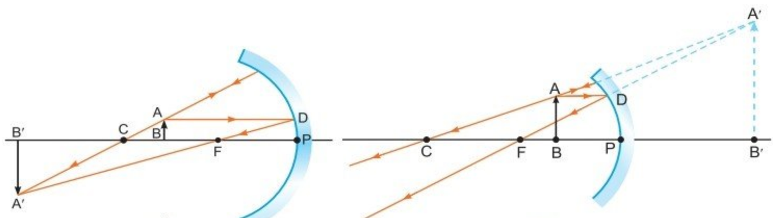
[CBSE Marking Scheme 2019 (55/5/1)]

Q. 15. An object is placed in front of a concave mirror of focal length of 12 cm. There are two possible positions of the object for which the image formed is three times the size of the object.

(*a*) Draw the ray diagram for the each case, and

(*b*) Find the distance between the two positions of the object. *[CBSE 2020 (55/4/2)]*

Ans. (*a*) Concave mirror forms magnified image for the following positions of object.



(*i*) (*ii*)

(*b*) Given, $f = -12$ cm

If $m = -3$ (Real and inverted)

$\therefore \quad m = \frac{-v}{u} = -3$

$v = 3u$

Using mirror formula,

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \qquad \Rightarrow \frac{1}{3u} + \frac{1}{u} = \frac{1}{f}$$

$$\Rightarrow \quad \frac{4}{3u} + \frac{1}{u} = \frac{1}{f} \qquad \Rightarrow \frac{4}{3u} = \frac{1}{f}$$

$$\therefore \quad u = \frac{4f}{3} = \frac{4}{3} \times -12 \text{ cm} = -16 \text{ cm.}$$

If $m = +3$ (Virtual and errect)

Again using mirror formula,

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \quad \Rightarrow \quad \frac{-1}{3u} + \frac{1}{u} = \frac{1}{f}$$

$$\Rightarrow \quad \frac{2}{3u} = \frac{1}{f} \quad \Rightarrow \quad u = \frac{2}{3} \times f = \frac{2}{3} \times (-12)$$

$$= -8 \text{ cm}$$

Distance between two positions of object $= (16 - 8)$ cm $=$ **8 cm**

Q. 16. A concave mirror forms a real image of an object kept at a distance 9 cm from it. If the object is taken away from the mirror by 6 cm, the image size reduces to $\frac{1}{4}$ th of its previous size. Find the focal length of the mirror. *[CBSE 2020 (55/4/3)]*

Ans. From Given, $u_1 = -9$ cm, $u_2 = -(9 + 6)$ cm $= -15$ cm

From magnification, $m = \dfrac{f}{f-u} = \dfrac{h_i}{h_0}$

$$(h_i)_2 = \frac{1}{4}(h_i)_1 \text{ (Given)}$$

$$\Rightarrow \quad \frac{f}{f-u_2} = \left(\frac{f}{f-u_1}\right)\frac{1}{4}$$

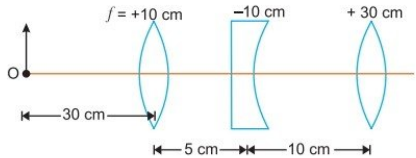
$$\Rightarrow \qquad \frac{f}{f-(-15)} = \frac{f}{[f-(-9)]}\frac{1}{4}$$

$$\Rightarrow \qquad f + 15 = 4\,(f + 9)$$

$$\Rightarrow \qquad 3f = 15 - 4 \times 9 = 15 - 36$$

$$\therefore \qquad f = \frac{-21}{3} = \mathbf{-7\ cm}$$

Q. 17. Find the position of the image formed of an object 'O' by the lens combination given in the figure. *[2019 (55/4/1)]*



Ans. For first lens, $u_1 = -30$ cm, $f_1 = +10$ cm

$\therefore$ From lens formula, $\dfrac{1}{f_1} = \dfrac{1}{v_1} - \dfrac{1}{u_1}$

$$\Rightarrow \qquad \frac{1}{v_1} = \frac{1}{f_1} + \frac{1}{u_1} = \frac{1}{10} - \frac{1}{30} = \frac{3-1}{30}$$

$$\Rightarrow \qquad v_1 = 15 \text{ cm}$$

The image formed by the first lens serves as the object for the second. This is at a distance of $(15 - 5)$ cm $= 10$ cm to the right of the second lens. Though the image is real, it serves as a virtual object for the second lens, which means that the rays appear to come from it for the second lens.

For second lens, $f_2 = -10$ cm, $u_2 = 15 - 5 = +10$ cm

$$\therefore \qquad \frac{1}{v_2} = \frac{1}{f_2} + \frac{1}{u_2} = -\frac{1}{10} + \frac{1}{10} \quad \Rightarrow \quad v_2 = \infty$$

The virtual image is formed at an infinite distance to the left of the second lens. This acts as an object for the third lens.

For third lens, $f_3 = +30$ cm, $u_3 = \infty$

From lens formula, $\dfrac{1}{v_2} = \dfrac{1}{f_3} + \dfrac{1}{u_3} = \dfrac{1}{30} + \dfrac{1}{\infty}$

$$\therefore \qquad v_3 = \mathbf{30\ cm}$$

The final image is formed at a distance 30 cm to the right of third lens.

Q. 18. **(*i*) A screen is placed at a distance of 100 cm from an object. The image of the object is formed on the screen by a convex lens for two different locations of the lens separated by 20 cm. Calculate the focal length of the lens used.**

(*ii*) A converging lens is kept coaxially in contact with a diverging lens - both the lenses being of equal focal length. What is the focal length of the combination? *[CBSE (North) 2016]*

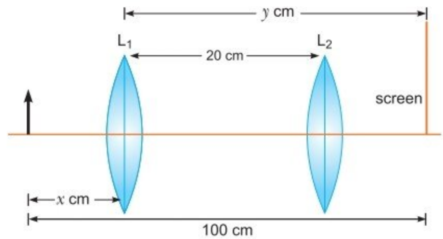
Ans. (*i*) For first position of the lens, we have

$$\frac{1}{f} = \frac{1}{y} - \frac{1}{(-x)} \qquad \Rightarrow \qquad \frac{1}{f} = \frac{1}{y} + \frac{1}{x} \qquad \text{...}(i)$$

For second position of lens, we have

$$\frac{1}{f} = \frac{1}{y-20} - \frac{1}{[-(x+20)]}$$

$$\frac{1}{f} = \frac{1}{y-20} + \frac{1}{x+20} \qquad \text{...}(ii)$$



From (*i*) and (*ii*), we have

$$\frac{1}{y}+\frac{1}{x}=\frac{1}{(y-20)}+\frac{1}{(x+20)}$$

$$\frac{x+y}{xy}=\frac{(x+20)+(y-20)}{(y-20)(x+20)}$$

$$\frac{x+y}{xy}=\frac{x+y}{(y-20)(x+20)}$$

$\therefore$ $xy = (y-20)(x+20)$

$\Rightarrow$ $xy = xy - 20x + 20y - 400$

$\Rightarrow$ $20x - 20y = -400$

$\therefore$ $x - y = -20$

Also, $x + y = 100$

On solving, we have

$x = 40$ cm and $y = 60$ cm

$$\therefore \quad \frac{1}{f}=\frac{1}{60}-\frac{1}{-40}=\frac{5}{120} \quad \Rightarrow f = \mathbf{24cm}$$

(*ii*) Let focal length of the combination be f.

$$\therefore \quad \frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}$$

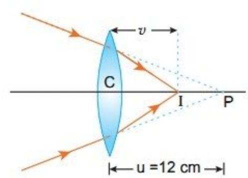
$$\Rightarrow \quad \frac{1}{f}=\frac{1}{f}+\left(-\frac{1}{f}\right)$$

$$\Rightarrow \quad \frac{1}{f}=0 \Rightarrow f = \textbf{infinite.}$$

Q. 19. A beam of light converges to a point *P*. A lens is placed in the path of the convergent beam 12 cm from *P*. At what point does the beam converge if the lens is (*a*) a convex lens of focal length 20 cm, (*b*) a concave lens of focal length 16 cm? [*NCERT*]

Ans. (*a*) Point *P* acts as a virtual object for convex lens.

Given $u = +12$ cm, $f = +20$ cm



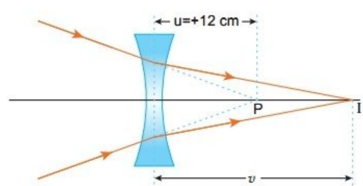
$$\therefore \frac{1}{f}=\frac{1}{v}-\frac{1}{u} \text{ gives } \frac{1}{v}=\frac{1}{f}+\frac{1}{u}=\frac{1}{20}+\frac{1}{12}$$

$$=\frac{3+5}{60}$$

$$\Rightarrow \quad v=\frac{60}{8}=\mathbf{7.5\ cm}$$

This implies that the image is formed to the right of the lens and is real.

(*b*) In this case, $u = +12$ cm, $f = -16$ cm,



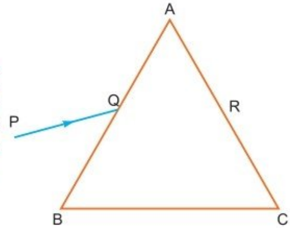
$$\therefore \frac{1}{f}=\frac{1}{v}-\frac{1}{u} \text{ gives } \frac{1}{v}=\frac{1}{f}+\frac{1}{u}$$

$$=-\frac{1}{16}+\frac{1}{12}=\frac{-3+4}{48}$$

$v = \mathbf{48\ cm}$

This shows that the image is formed at a distance of 48 cm to the right of concave lens and is real.

Q. 20. A ray PQ incident on the face AB of a prism ABC, as shown in the figure, emerges from the face AC such that $AQ = AR$. Draw the ray diagram showing the passage of the ray through the prism. If the angle of the prism is 60° and refractive index of the material of the prism is $\sqrt{3}$, determine the values of angle of incidence and angle of deviation. *[CBSE Panchkula 2015]*



Ans. Here, $\angle A = 60°$ and $n = \sqrt{3}$

We have, $i + e = A + \delta$

Since QR is parallel to BC hence this is the case of minimum deviation.

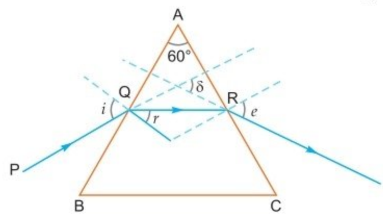
$i = e$

$2i = 60 + \delta$ ...(*i*)

$2r = 60 \Rightarrow r = \dfrac{60}{2} = 30°$

$n = \dfrac{\sin i}{\sin r} \Rightarrow \sqrt{3} = \dfrac{\sin i}{\sin 30°}$

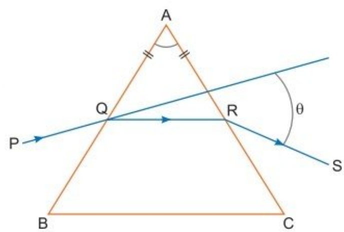
$\sin i = \dfrac{\sqrt{3}}{2} \Rightarrow \angle i = \mathbf{60°}$



Substitute in (*i*), we have

$120 = 60 + \delta \Rightarrow \delta = \mathbf{60°}$

Q. 21. A ray PQ incident on the refracting face BA is refracted in the prism BAC as shown in the figure and emerges from the other refracting face AC as RS such that $AQ = AR$. If the angle of prism $A = 60°$ and refractive index of material of prism is $\sqrt{3}$, calculate angle θ. *[CBSE North 2016]*



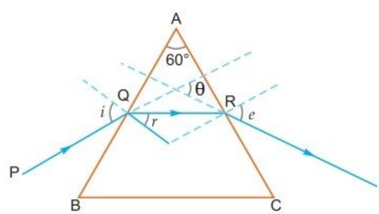
Ans. Given, $AQ = AR$, we have

$QR \,||\, BC$

At the minimum deviation, the refracted ray inside the prism becomes parallel to its base.

$\therefore$ θ is the angle of minimum deviation.

$$n = \frac{\sin\left(\dfrac{A+\theta}{2}\right)}{\sin\left(\dfrac{A}{2}\right)} \Rightarrow \sqrt{3} = \frac{\sin\left(\dfrac{60° + \theta}{2}\right)}{\sin 30°}$$



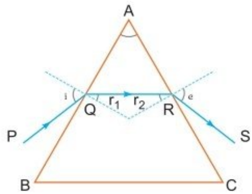
$$\sin\left(\frac{60° + \theta}{2}\right) = \frac{\sqrt{3}}{2} \Rightarrow \sin\left(\frac{60° + \theta}{2}\right) = \sin 60°$$

$$\Rightarrow \frac{60° + \theta}{2} = 60° \Rightarrow \theta = \mathbf{60°}$$

Q. 22. Figure shows a ray of light passing through a prism. If the refracted ray QR is parallel to the base BC, show that

(*i*) $r_1 = r_2 = A/2$,

(*ii*) angle of minimum deviation, $D_m = 2i - A$. *[CBSE (F) 2014]*



Ans. (*i*) We know that

$$r_1 + r_2 = A$$

Since QR is parallel to BC

So, $\quad r_1 = r_2$ and $i = e$

Therefore, $2r_1$ or $2r_2 = A \quad \Rightarrow \quad r_1 = r_2 = A/2$

(*ii*) D_m = Deviation at the first face + Deviation of the second face

$= (i - r_1) + (e - r_2) = (i + e) - (r_1 + r_2)$

$= 2i - A \qquad (\because i = e)$

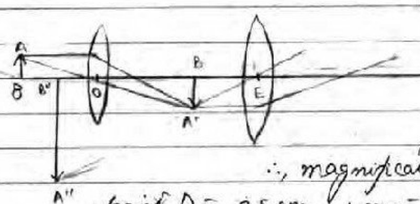
Q. 23. What is the difference in the construction of an astronomical telescope and a compound microscope? The focal lengths of the objective and eyepiece of a compound microscope are 1.25 cm and 5.0 cm, respectively. Find the position of the object relative to the objective in order to obtain an angular magnification of 30 when the final image is formed at the near point. **[*CBSE 2020 (55/2/1)*]**

Ans.

• The differences in the construction of an astronomical telescope and compound microscope.

In ~~a~~ compound microscope, the objective is of smaller aperture and smaller focal length than the eyepiece, but in an astronomical telescope, objective is larger than eyepiece and has a large focal length.

••



Focal length of objective, $f_0 = 1.25$ cm, f_e = Focal length of eyepiece = 5.00 cm.

∴ magnification for image at near point D = 25 cm : $m = -\frac{L}{f_0}\cdot\left(1 + D/f_e\right)$

where, L is tube length.

∵ magnification by eyepiece = $1 + D/f_e$,

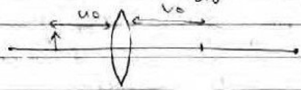
here, 'm' by eyepiece (me) = $1 + \frac{25}{5} = 1 + 5 = 6$.

∴ total magnification $m = m_0 \cdot m_e$

$\Rightarrow 30 = m_0 \cdot 6 \Rightarrow |m_0| = 5.$ ~~$\Rightarrow m_0 = -5$~~

~~$\therefore$ final image is formed at D,~~
~~$\therefore$ from lens formula in eyepiece,~~
~~$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \Rightarrow \frac{1}{-25} - \frac{1}{u} = \frac{1}{5} \Rightarrow \frac{1}{u} = -\frac{1}{5} - \frac{1}{25} = \frac{-6}{25}$~~
~~$\Rightarrow u = -\frac{25}{6}$~~

$\therefore m_0 = -5 \Rightarrow \frac{v_0}{u_0} = -5 \Rightarrow v_0 = -5u_0.$ [v_0 is image distance, u_0 is object distance, for objective]



$\therefore$ for objective,
$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

~~$\Rightarrow \frac{1}{v_0} - \frac{1}{u_0} = \frac{1}{1.25} = \frac{4}{5}$~~
~~$\Rightarrow -\frac{1}{5u_0} + \frac{1}{u_0} = \frac{4}{5} \Rightarrow \frac{-1+5}{5u_0} = \frac{4}{5} \Rightarrow \frac{4}{5u_0} = \frac{4}{5}$~~
~~$\Rightarrow u_0 = 1.$~~

$\therefore \frac{1}{v_0} - \frac{1}{u_0} = \frac{1}{1.25}$
$\Rightarrow \frac{1}{-5u_0} - \frac{1}{u_0} = \frac{4}{5} \Rightarrow \frac{6}{5u_0} = \frac{4}{5} \Rightarrow -\frac{5u_0}{6} = \frac{5}{4}.$
$\Rightarrow u_0 = -\frac{30}{20} = -\frac{3}{2}.$

$\therefore$ distance of the object from the objective $= 1.50$ cm (Ans)

[*Topper's Answer 2020*]

Q. 24. The total magnification produced by a compound microscope is 20. The magnification produced by the eye piece is 5. The microscope is focussed on a certain object. The distance between the objective and eyepiece is observed to be 14 cm. If least distance of distinct vision is 20 cm, calculate the focal length of the objective and the eye piece. **[*CBSE Delhi 2014*]**

Ans. Here, $M = -20$, $m_e = 5$, $v_e = -20$ cm

For eyepiece, $m_e = \frac{v_e}{u_e}$

$$\Rightarrow \quad 5 = \frac{-20}{u_e} \quad \Rightarrow \quad u_e = \frac{-20}{5} = -4 \text{ cm}$$

Using lens formula,

$$\frac{1}{v_e} - \frac{1}{u_e} = \frac{1}{f_e} \quad \Rightarrow \quad -\frac{1}{20} + \frac{1}{4} = \frac{1}{f_e}$$

$$\Rightarrow \quad \frac{-1+5}{20} = \frac{1}{f_e} \quad \Rightarrow \quad f_e = \mathbf{5\ cm}$$

Now, total magnification

$$M = m_e \times m_o$$

$$-20 = 5 \times m_o \quad \Rightarrow \quad m_o = -4$$

Also $\quad |v_o| + |u_e| = 14$

$$|v_o| + |-4| = 14$$

$$v_o = 14 - 4 = 10 \text{ cm}$$

$$m_o = 1 - \frac{v_o}{f_o} \quad \Rightarrow \quad -4 = 1 - \frac{10}{f_o}$$

$$-5 = -\frac{10}{f_0} \quad \Rightarrow \quad f_o = \mathbf{2\ cm.}$$

Q. 25. A small telescope has an objective lens of focal length 150 cm and eyepiece of focal length 5 cm. What is the magnifying power of the telescope for viewing distant objects in normal adjustment?

If this telescope is used to view a 100 m tall tower 3 km away, what is the height of the image of the tower formed by the objective lens? **[*CBSE Allahabad 2015*]**

Ans. If the telescope is in normal adjustment, *i.e.*, the final image is at infinity.

$$M = \frac{f_o}{f_e}$$

Since $f_o = 150\text{ cm}, f_e = 5\text{ cm}$

$\therefore$ $$M = \frac{150}{5} = \mathbf{30}$$

If tall tower is at distance 3 km from the objective lens of focal length 150 cm. It will form its image at distance v_o So,

Using Lens formula,

$$\frac{1}{f_o} = \frac{1}{v_o} - \frac{1}{u_o}$$

$\Rightarrow$ $$\frac{1}{150\text{ cm}} = \frac{1}{v_o} - \frac{1}{(-3\text{ km})}$$

$\Rightarrow$ $$\frac{1}{v_o} = \frac{1}{1.5\text{ m}} - \frac{1}{3000\text{ m}}$$

$\therefore$ $$v_o = \frac{3000\times1.5}{3000-1.5} = \frac{4500}{2998.5} = 1.5\text{ m}$$

Magnification, $m_o = \dfrac{I}{O} = \dfrac{h_i}{h_o} = \dfrac{v_o}{u_o}$

$\Rightarrow$ $$\frac{h_i}{100\text{ m}} = \frac{1.5\text{ m}}{3\text{ km}} = \frac{1.5}{3000}$$

$\Rightarrow$ $$h_i = \frac{1.5\times100}{3000} = \frac{1}{20}\text{ m}$$

$\therefore$ $$h_i = \mathbf{0.05\ m}$$

Q. 26. An amateur astronomer wishes to estimate roughly the size of the sun using his crude telescope consisting of an objective lens of focal length 200 cm and an eyepiece of focal length 10 cm. By adjusting the distance of the eyepiece from the objective, he obtains an image of the sun on a screen 40 cm behind the eyepiece. The diameter of the sun's image is measured to be 6.0 cm. Estimate the sun's size, given that the average earth-sun distance is 1.5×10^{11} m.

[*CBSE 2019 (55/5/1)*]

Ans. For eyepiece.

Given, $v_e = 40\text{ cm}, f_e = 10\text{ cm}$

$\Rightarrow$ $$\frac{1}{v_e} - \frac{1}{u_e} = \frac{1}{f_e}$$

or $$\frac{1}{u_e} = \frac{1}{v_e} - \frac{1}{f_e} = \frac{1}{40} - \frac{1}{10} \quad \Rightarrow \quad u_e = \frac{-40}{3}\text{ cm}$$

Magnification produced by eye piece is

$$m_e = \frac{v_e}{|u_e|} = \frac{40}{40/3} = 3$$

Diameter of the image formed by the objective is

$$d = 6/3 = 2\text{ cm}$$

If D be the diameter of the sun then the angle subtended by it on the objective will be

$$a = \frac{D}{1.5 \times 10^{11}} \text{ rad}$$

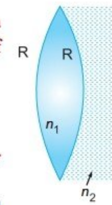
Angle subtended by the image at the objective

= angle subtended by the sun

$$\therefore \qquad \alpha = \frac{\text{Size of image}}{f_0} = \frac{2}{200} = \frac{1}{100} \text{ rad}$$

$$\therefore \qquad \frac{D}{1.5 \times 10^{11}} = \frac{1}{100} \quad \Rightarrow D = \mathbf{1.5 \times 10^9 \text{ m}}$$

Q. 27. A biconvex lens with its two faces of equal radius of curvature R is made of a transparent medium of refractive index n_1. It is kept in contact with a medium of refractive index n_2 as shown in the figure.



(a) Find the equivalent focal length of the combination.

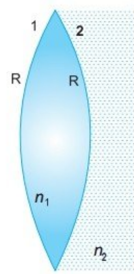
(b) Obtain the condition when this combination acts as a diverging lens.

(c) Draw the ray diagram for the case $n_1 > (n_2 + 1)/2$, when the object is kept far away from the lens. Point out the nature of the image formed by the system.

[*CBSE Patna 2015*] [*HOTS*]

Ans. (*a*) If refraction occurs at first surface

$$\frac{n_1}{v_1} - \frac{1}{u} = \frac{(n_1 - 1)}{R} \qquad \text{...(i)}$$



If refraction occurs at second surface, and the image of the first surface acts as an object

$$\frac{n_2}{v} - \frac{n_1}{v_1} = \frac{n_2 - n_1}{-R} \qquad \text{...(ii)}$$

On adding equation (*i*) and (*ii*), we get

$$\frac{n_2}{v} - \frac{1}{u} = \frac{2n_1 - n_2 - 1}{R}$$

If rays are coming from infinity, *i.e.*, $u = -\infty$ then $v = f$

$$\frac{n_2}{f} + \frac{1}{\infty} = \frac{2n_1 - n_2 - 1}{R} \quad \Rightarrow f = \frac{n_2 R}{2n_1 - n_2 - 1}$$

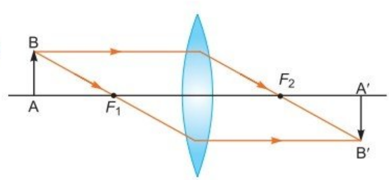
(*b*) If the combination behave as a diverging system then $f < 0$. This is possible only when

$$2n_1 - n_2 - 1 < 0$$

$$\Rightarrow \qquad 2n_1 < n_2 + 1$$

$$\Rightarrow \qquad n_1 < \frac{(n_2 + 1)}{2}$$

(*c*) If the combination behaves as a converging lens then $f > 0$. It is possible only when



$$2n_1 - n_2 - 1 > 0$$

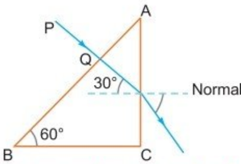
$$\Rightarrow \qquad 2n_1 - > n_2 + 1$$

$$\Rightarrow \qquad n_1 > \frac{(n_2 + 1)}{2}$$

Nature of the image formed is real.

$\angle i$ on face AC is 30° which is less than $\angle i_c$. Hence, the ray get refracted.

And, applying Snell's law at face AC,

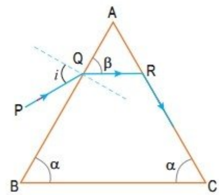


$$\sin 30° \times \frac{3}{2} = \sin r \times 1$$

$$\Rightarrow \quad \sin r = \frac{1}{2} \times \frac{3}{2} \quad \Rightarrow \quad r = \sin^{-1}\left(\frac{3}{4}\right) = \sin^{-1}(0.75) = 48.6°$$

And, clearly $r > i$, as ray passes from denser to rarer medium.

Q. 31. A ray of light incident on the face AB of an isosceles triangular prism makes an angle of incidence (i) and deviates by angle β as shown in the figure. Show that in the position of minimum deviation $\angle\beta = \angle\alpha$. Also find out the condition when the refracted ray QR suffers total internal reflection. **[*CBSE 2019 (55/2/2)*]**



Ans. For minimum deviation

$$r_1 + r_2 = A; \qquad r_1 = r_2$$

Also, $\quad (90 - \beta) + (90 - \beta) = A$

$$\Rightarrow \quad 180 - 2\beta = A$$

$$\Rightarrow \quad 2\beta = 180 - A$$

$$\Rightarrow \quad 2\beta = 2\alpha$$

$$\Rightarrow \quad \beta = \alpha$$

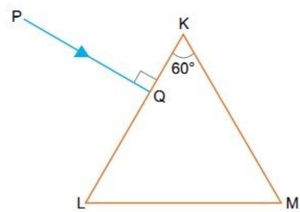
We have, $r_1 + r_2 = A$

$$\Rightarrow \quad r_1 + i_c = A \qquad \text{(Take } r_2 = i_c\text{)}$$

$$\Rightarrow \quad i_c = A - r_1$$

$$\therefore \quad i_c = A - (90 - \beta)$$

Q. 32. A triangular prism of refracting angle 60° is made of a transparent material of refractive index $2/\sqrt{3}$. A ray of light is incident normally on the face KL as shown in the figure. Trace the path of the ray as it passes through the prism and calculate the angle of emergence and angle of deviation. **[*CBSE 2019 (55/2/1)*]**



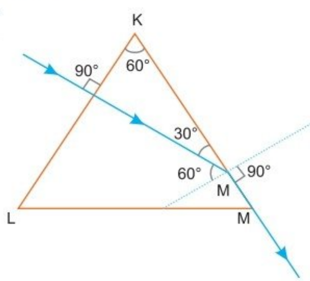
Ans. When light ray incident on face KL, it is pass undeviated, because it is normal to the surface and incident on face KM. The angle of incidence for face KM is equal to 60°.

$$\frac{\sin 60°}{\sin r} = \frac{n_2}{n_1} \qquad \left[\begin{array}{l} n_2 = \text{Second medium} = \text{air} \\ n_1 = \text{Glass medium} = 2/\sqrt{3} \end{array}\right.$$

$$\frac{\sin 60°}{\sin r} = \frac{1}{2/\sqrt{3}} = \frac{\sqrt{3}}{2}$$

$$\Rightarrow \quad \sin r = \frac{\sin 60°}{\frac{\sqrt{3}}{2}} = 1$$

$$\sin r = 1 \quad \Rightarrow \quad r = 90°$$



Angle of emergence = **90°**

Angle of deviation = **30°**

Long Answer Questions

Each of the following questions are of 5 marks.

Q. 1. An object is placed in front of a concave mirror. It is observed that a virtual image is formed. Draw the ray diagram to show the image formation and hence derive the mirror equation $\frac{1}{f}=\frac{1}{u}+\frac{1}{v}$. **[*CBSE 2020 (55/1/1)*]**

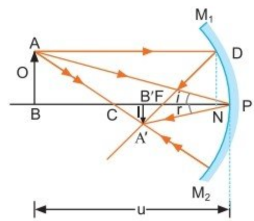
OR

(*i*) Derive the mirror formula. What is the corresponding formula for a thin lens?

(*ii*) Draw a ray diagram to show the image formation by a concave mirror when the object is kept between its focus and the pole. Using this diagram, derive the magnification formula for the image formed. **[*CBSE Delhi 2011*]**

Ans. (*i*) **Mirror Formula:** M_1M_2 is a concave mirror having pole P, focus F and centre of curvature C.

An object AB is placed in front of mirror with point B on the principal axis. The image formed by mirror is $A'B'$. The perpendicular dropped from point of incidence D on principal axis is DN



In ΔABC and $\Delta A'B'C$

$\angle ABC = \angle A'B'C$ (each equal to 90°)

$\angle ACB = \angle A'CB'$ (opposite angles)

Both triangles are similar.

$$\therefore \frac{AB}{A'B'}=\frac{BC}{B'C} \quad \ldots(i)$$

Now in ΔDNF and $\Delta A'B'F$

$\angle DNF = \angle A'B'F$ (each equal to 90°)

$\angle DFN = \angle A'FB'$ (opposite angles)

$\therefore$ Both triangles are similar

$$\frac{DN}{A'B'}=\frac{FN}{B'F} \text{ or } \frac{AB}{A'B'}=\frac{FN}{B'F} (\because AB = DN) \quad \ldots(ii)$$

Comparing (*i*) and (*ii*), we get

$$\frac{BC}{B'C}=\frac{FN}{B'F} \quad \ldots(iii)$$

If aperture of mirror is very small, the point N will be very near to P, so $FN = FP$

$$\therefore \frac{BC}{B'C}=\frac{FP}{B'F} \text{ or } \frac{PB-PC}{PC-PB'}=\frac{FP}{PB'-PF} \quad \ldots(iv)$$

By sign convention

Distance of object from mirror $PB = -u$

Distance of image from mirror $PB' = -v$

Focal length of mirror $PF = -f$

Radius of curvature of mirror $PC = -R = -2f$

Substituting these values in (*iv*), we get

$$\frac{-u-(-2f)}{-2f-(-v)}=\frac{-f}{-v-(-f)}$$

$$\frac{-u+2f}{-2f+v} = \frac{-f}{-v+f}$$

$\Rightarrow \; 2f^2 - vf = -uf + uv + 2f^2 - 2vf \quad$ or $\quad vf + uf = uv$

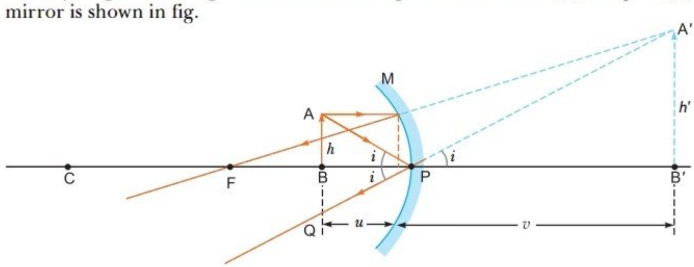
Dividing both sides by uvf we get

$$\mathbf{\frac{1}{f} = \frac{1}{u} + \frac{1}{v}}$$

The corresponding formula for thin lens is

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

(ii) The ray diagram of image formation for an object between focus (F) and pole (P) of a concave mirror is shown in fig.



Magnification: $m = \dfrac{\text{Size of image } (A'B')}{\text{Size of object } (AB)}$

From fig. $\angle APB = \angle BPQ = i$

Also, $\angle BPQ = \angle A'PB' = i$

In $\Delta\, APB, \tan i = \dfrac{AB}{BP}$ ...*(i)*

In $\Delta\, A'PB', \tan i = \dfrac{A'B'}{B'P}$ ...*(ii)*

From *(i)* and *(ii)*,

$$\frac{AB}{BP} = \frac{A'B'}{B'P}$$

$\Rightarrow$ Magnification, $m = \dfrac{A'B'}{AB} = \dfrac{B'P}{BP}$

or $m = \dfrac{v}{-u}$ or $\boldsymbol{m = -\dfrac{v}{u}}$

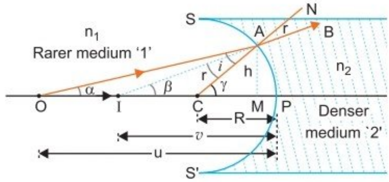
Q. 2. With the help of a ray diagram, show the formation of image of a point object due to refraction of light at a spherical surface separating two media of refractive indices n_1 and n_2 ($n_2 > n_1$) respectively. Using this diagram, derive the relation

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_1 - n_2}{R}$$

Write the sign conventions used. What happens to the focal length of convex lens when it is immersed in water?

Ans. Formula for Refraction at Spherical Surface

Concave Spherical Surface: Let SPS' be a spherical refracting surface, which separates media '1' and '2'. Medium '1' is rarer and medium '2' is denser. The refractive indices of media '1' and '2' are n_1 and n_2 respectively ($n_1 < n_2$). Let P be the pole and C the centre of curvature and PC the principal axis of spherical refracting surface.



O is a point-object on the principal axis. An incident ray OA, after refraction at A on the spherical surface bends towards the normal CAN and moves along AB. Another incident ray OP falls on the surface normally and hence passes undeviated after refraction. These two rays, when produced backward meet at point I on principal axis. Thus I is the virtual image of O.

Let angle of incidence of ray OA be i and angle of refraction be r *i.e.*,

$$\angle OAC = i \quad \text{and} \quad \angle NAB = r$$

Let $\angle AOP = \alpha$, $\angle AIP = \beta$ and $\angle ACP = \gamma$

In triangle OAC $\quad \gamma = \alpha + i$ or $i = \gamma - \alpha$ ...(*i*)

In triangle AIC, $\quad \gamma = \beta + r$ or $r = \gamma - \beta$ ...(*ii*)

From Snell's law $\quad \dfrac{\sin i}{\sin r} = \dfrac{n_2}{n_1}$ ...(*iii*)

If point A is very near to P, then angles i, r, α, β, γ will be very small, therefore $\sin i = i$ and $\sin r = r$

Substituting values of i and r from (*i*) and (*ii*) we get

$$\frac{\gamma - \alpha}{\gamma - \beta} = \frac{n_2}{n_1} \quad \text{or} \quad n_1(\gamma - \alpha) = n_2(\gamma - \beta) \qquad \text{...(iv)}$$

The length of perpendicular AM dropped from A on the principal axis is h *i.e.*, $AM = h$. As angles α, β and γ are very small, therefore

$$\tan\alpha = \alpha, \quad \tan\beta = \beta, \quad \tan\gamma = \gamma$$

Substituting these values in equation (*iv*)

$$n_1(\tan\gamma - \tan\alpha) = n_2(\tan\gamma - \tan\beta) \qquad \text{...(v)}$$

As point A is very close to P, point M is coincident with P

$$\tan\alpha = \frac{\text{Perpendicular}}{\text{Base}} = \frac{AM}{MO} = \frac{h}{PO}$$

$$\tan\beta = \frac{AM}{MI} = \frac{h}{PI}, \quad \tan\gamma = \frac{AM}{MC} = \frac{h}{PC}$$

Substituting this value in (*v*), we get

$$n_1\left(\frac{h}{PC} - \frac{h}{PO}\right) = n_2\left(\frac{h}{PC} - \frac{h}{PI}\right)$$

or $$\frac{n_1}{PC} - \frac{n_1}{PO} = \frac{n_2}{PC} - \frac{n_2}{PI} \qquad \text{...(vi)}$$

Let u, v and R be the distances of object O, image I and centre of curvature C from pole P. By sign convention PO, PI and PC are negative, *i.e.*, $u = -PO$, $v = -PI$ and $R = -PC$

Substituting these values in (*vi*), we get

$$\frac{n_1}{(-R)} - \frac{n_1}{(-u)} = \frac{n_2}{(-R)} - \frac{n_2}{(-v)} \quad \text{or} \quad \frac{n_1}{R} - \frac{n_1}{u} = \frac{n_2}{R} - \frac{n_2}{v}$$

or $$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$$

Sign Conventions:

(*i*) All the distances are measured from optical centre (*P*) of the lens.

(*ii*) Distances measured in the direction of incident ray of light are taken positive and vice-versa.

As we know

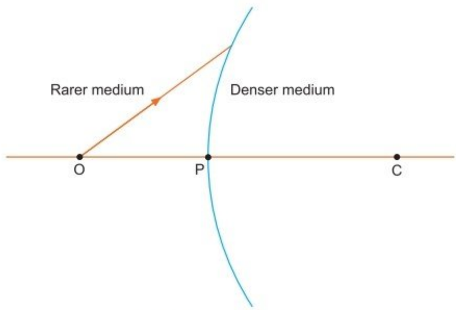
$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

When convex lens is immersed in water, refractive index n decreases and hence focal length will increase *i.e.*, the focal length of a convex lens increases when it is immersed in water.

Q. 3. A spherical surface of radius of curvature *R*, separates a rarer and a denser medium as shown in the figure.

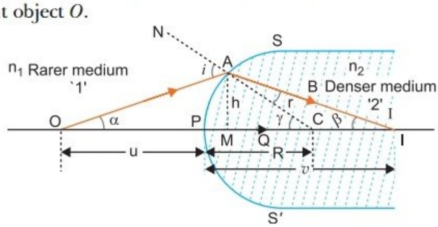
Complete the path of the incident ray of light, showing the formation of a real image. Hence derive the relation connecting object distance '*u*', image distance '*v*', radius of curvature *R* and the refractive indices n_1 and n_2 of two media. **[*CBSE 2023 (55/1/1)*]**

Briefly explain, how the focal length of a convex lens changes, with increase in wavelength of incident light.



[***CBSE Delhi 2014; Central 2016; (F) 2017; Sample Paper 2016***]

Ans. Relation of object and image distances of a convex spherical surface: Let *SPS′* be the convex spherical refracting surface, separating the two media of refractive indices n_1 and n_2 respectively ($n_1 < n_2$) *i.e.*, medium '1' is rarer and medium '2' is denser. Let *P* be the pole, *C* the centre of curvature and *PC* the principal axis of convex refracting surface. *O* is a distant point object on the principal axis. The ray *OA* starting from *O* is incident on point *A* of the spherical surface, *CAN* is normal at point *A* of the surface. Due to going from rarer to denser medium the ray *OA* deviates along the normal *CAN* and is refracted along the direction *AB*. The another ray *OP* starting from *O* is incident normally on the spherical surface and passes undeviated after refraction along *PQ*. Both the rays *AB* and *PQ* meet at point *I* on the principal axis, *i.e.*, *I* is the real image of point object *O*.



Let i be the angle of incidence of ray *OA* and r the angle of refraction in the denser medium *i.e.*, $\angle \text{OAN} = i$ and $\angle CAI = r$. Let $\angle AOP = \alpha$, $\angle AIP = \beta$ and $\angle ACP = \gamma$

In triangle *OAC*, $\quad i = \gamma + \alpha \quad$ ...(*i*)

In triangle AIC, $\gamma = \beta + r$ or $r = \gamma - \beta$ ...(ii)

From Snell's law $$\frac{\sin i}{\sin r} = \frac{n_2}{n_1}$$ ...(iii)

If point A is very close to P, then angles i, r, α, β and γ will be very small, therefore

$$\sin i = i \quad \text{and} \quad \sin r = r$$

From equation (iii),

$$\frac{i}{r} = \frac{n_2}{n_1}$$

Substituting values of i and r from (i) and (ii), we get

$$\frac{\gamma + \alpha}{\gamma - \beta} = \frac{n_2}{n_1} \text{ or } n_1(\gamma + \alpha) = n_2(\gamma - \beta) \quad ...(iv)$$

Let h be the height of perpendicular drawn from A on principal axis *i.e.*, $AM = h$. As α, β and γ are very small angles.

$$\tan \alpha = \alpha, \tan \beta = \beta \text{ and } \tan \gamma = \gamma$$

Substituting these values in (iv)

$$n_1(\tan \gamma + \tan \alpha) = n_2 (\tan \gamma - \tan \beta) \quad ...(v)$$

As point A is very close to point P, point M is coincident with P.

From figure $$\tan \alpha = \frac{AM}{OM} = \frac{h}{OP}$$

$$\tan \beta = \frac{AM}{MI} = \frac{h}{PI}$$

$$\tan \gamma = \frac{AM}{MC} = \frac{h}{PC}$$

Substituting these values in (v), we get

$$n_1\left(\frac{h}{PC} + \frac{h}{OP}\right) = n_2\left(\frac{h}{PC} - \frac{h}{PI}\right)$$

or $$n_1\left(\frac{1}{PC} + \frac{1}{OP}\right) = n_2\left(\frac{1}{PC} - \frac{1}{PI}\right) \quad ...(vi)$$

If the distances of object O, image I, centre of curvature C from the pole be u, v and R respectively, then by sign convention PO is negative while PC and PI are positive. Thus,

$$u = -PO, \qquad v = +PI, \qquad R = +PC$$

Substituting these values in (vi), we get

$$n_1\left(\frac{1}{R} - \frac{1}{u}\right) = n_2\left(\frac{1}{R} - \frac{1}{v}\right)$$

or $$\frac{n_1}{R} - \frac{n_1}{u} = \frac{n_2}{R} - \frac{n_2}{v}$$

$\therefore$ $$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$$

The focal length of a convex lens is given by

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

According to Cauchy's formula

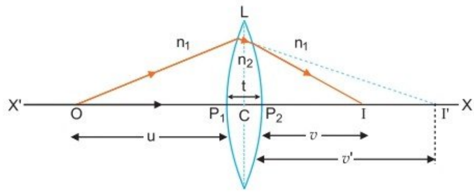
$$n = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4} + \ldots$$

Then n varies inversely as λ.

When wavelength increases, the refractive index n decreases; so focal length of lens increases with increase of wavelength.

Q. 4. Draw a ray diagram for formation of image of a point object by a thin double convex lens having radii of curvature R_1 and R_2. Hence, derive lens maker's formula for a double convex lens. State the assumptions made and sign convention used. **[*CBSE (F) 2013, (Central) 2016, 2020 (55/2/1)*]**

Ans. **Lens Maker's Formula:** Suppose L is a thin lens. The refractive index of the material of lens is n_2 and it is placed in a medium of refractive index n_1. The optical centre of lens is C and $X'X$ is the principal axis. The radii of curvature of the surfaces of the lens are R_1 and R_2 and their poles are P_1 and P_2 The thickness of lens is t, which is very small. O is a point object on the principal axis of the lens. The distance of O from pole P_1 is u. The first refracting surface forms the image of O at I' at a distance v' from P_1. From the refraction formula at spherical surface



$$\frac{n_2}{v'} - \frac{n_1}{u} = \frac{n_2 - n_1}{R_1} \qquad ...(i)$$

The image I' acts as a virtual object for second surface and after refraction at second surface, the final image is formed at I. The distance of I from pole P_2 of second surface is v. The distance of virtual object (I') from pole P_2 is $(v' - t)$.

For refraction at second surface, the ray is going from second medium (refractive index n_2) to first medium (refractive index n_1), therefore from refraction formula at spherical surface

$$\frac{n_1}{v} - \frac{n_2}{(v' - t)} = \frac{n_1 - n_2}{R_2} \qquad ...(ii)$$

For a thin lens t is negligible as compared to v' therefore from (*ii*)

$$\frac{n_1}{v} - \frac{n_2}{v'} = -\frac{n_2 - n_1}{R_2} \qquad ...(iii)$$

Adding equations (*i*) and (*iii*), we get

$$\frac{n_1}{v} - \frac{n_1}{u} = (n_2 - n_1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

or
$$\frac{1}{v} - \frac{1}{u} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

i.e.
$$\frac{1}{v} - \frac{1}{u} = ({}_1n_2 - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad ...(iv)$$

where ${}_1n_2 = \frac{n_2}{n_1}$ is refractive index of second medium (*i.e.*, medium of lens) with respect to first medium.

If the object O is at infinity, the image will be formed at second focus *i.e.*,

if $u = \infty$, $v = f_2 = f$

Therefore from equation (*iv*),

$$\frac{1}{f}-\frac{1}{\infty}=({}_1n_2-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

i.e.,
$$\frac{1}{f}=({}_1n_2-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

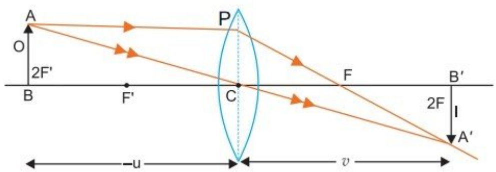
This formula is called ***Lens-Maker's formula.***

If first medium is air and refractive index of material of lens be n, then ${}_1n_2 = n$, therefore the modified above equation may be written as

$$\frac{1}{f}=(n-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

Q. 5. Draw a ray diagram to show the formation of real image of the same size as that of the object placed in front of a converging lens. Using this ray diagram establish the relation between u, v and f for this lens.

Ans. **Thin Lens Formula:** Suppose an object AB of finite size is placed normally on the principal axis of a thin convex lens (fig.). A ray AP starting from A parallel to the principal axis, after refraction through the lens, passes through the second focus F. Another ray AC directed towards the optical centre C of the lens, goes straight undeviated. Both the rays meet at A' Thus A' is the real image of A. The perpendicular $A'B'$ dropped from A' on the principal axis is the whole image of AB.



Let distance of object AB from lens $= u$

Distance of image $A'B'$ from lens $= v$

Focal length of lens $= f$. We can see that triangles ABC and $A'B'C'$ are similar

$$\frac{AB}{A'B'}=\frac{CB}{CB'} \qquad ...(i)$$

Similarly triangles PCF and $A'B'F$ are similar

$$\frac{PC}{A'B'}=\frac{CF}{FB'}$$

But $PC = AB$

$$\frac{AB}{A'B'}=\frac{CF}{FB'} \qquad ...(ii)$$

From (*i*) and (*ii*), we get $\frac{CB}{CB'}=\frac{CF}{FB'}$ ...(*iii*)

From sign convention, $CB = -u$, $CB' = v$, $CF = f$

and $FB' = CB' - CF = v - f$

Substituting this value in (*iii*), we get, $-\frac{u}{v}=\frac{f}{v-f}$

or $-u(v-f)=\frac{1}{f}vf$ or $-uv+uf=vf$

Dividing throughout by uvf, we get $\boldsymbol{\frac{1}{f}=\frac{1}{v}-\frac{1}{u}}$

Q. 6. Derive the lens formula $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$ for a thin concave lens, using the necessary ray diagram.

Ans. The formation of image by a concave lens '*L*' is shown in fig. *AB* is object and *A′ B′* is the image. Triangles *ABO* and *A′ B′ O* are similar

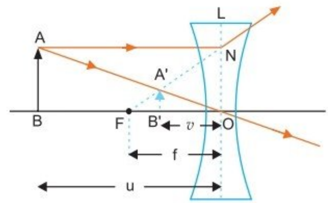
$$\frac{AB}{A'B'}=\frac{OB}{OB'} \qquad \ldots(i)$$

Also triangles *NOF* and *A′ B′ F* are similar

$$\frac{NO}{A'B'}=\frac{OF}{FB'}$$

But $NO = AB$

$$\frac{AB}{A'B'}=\frac{OF}{FB'} \qquad \ldots(ii)$$



Comparing equation (*i*) and (*ii*)

$$\frac{OB}{OB'}=\frac{OF}{FB'} \Rightarrow \frac{OB}{OB'}=\frac{OF}{OF-OB'}$$

Using sign conventions of coordinate geometry

$$OB = -u,\ OB' = -v,\ OF = -f$$

$$\frac{-u}{-v}=\frac{-f}{-f+v} \Rightarrow uf-uv=vf$$

$$\Rightarrow \qquad uv = uf - vf$$

Dividing throughout by *uvf*, we get

$$\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$$

This is the required lens formula.

Q. 7. Define power of a lens. Write its units. Deduce the relation $\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}$ for two thin lenses kept in contact coaxially. ***[CBSE (F) 2012, 2019 (55/4/3), 2020 (55/4/1)]***

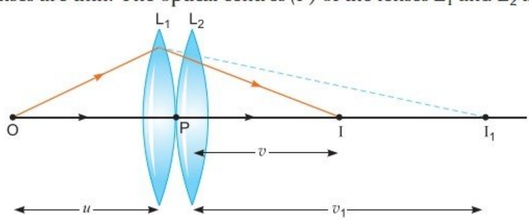
Ans. **Power of lens:** It is the reciprocal of focal length of a lens.

$$P=\frac{1}{f}\ (f \text{ is in metre})$$

Unit of power of a lens is Diopter.

An object is placed at point O. The lens L_1 produces an image at I_1 which serves as a virtual object for lens L_2 which produces final image at I.

Given, the lenses are thin. The optical centres (P) of the lenses L_1 and L_2 is co-incident.



For lens L_1, we have

$$\frac{1}{v_1}-\frac{1}{u}=\frac{1}{f_1} \qquad \ldots(i)$$

For lens L_2, we have $\frac{1}{v}-\frac{1}{v_1}=\frac{1}{f_2}$ ...(*ii*)

Adding equations *(i)* and *(ii)*, we have

$$\frac{1}{v_1}-\frac{1}{u}+\frac{1}{v}-\frac{1}{v_1}=\frac{1}{f_1}+\frac{1}{f_2}$$

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f_1}+\frac{1}{f_2} \quad ...(iii)$$

If two lenses are considered as equivalent to a single lens of focal length f, then

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f} \quad ...(iv)$$

From equation *(iii)* and equation *(iv)*, we can write

$$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}$$

Q. 8. *(a)* **Draw the labelled ray diagram for the formation of image by a compound microscope. Derive an expression for its total magnification (or magnifying power), when the final image is formed at the near point.** [*CBSE Sample paper 2022, Term-2*] [*CBSE 2019 (55/5/1)*]

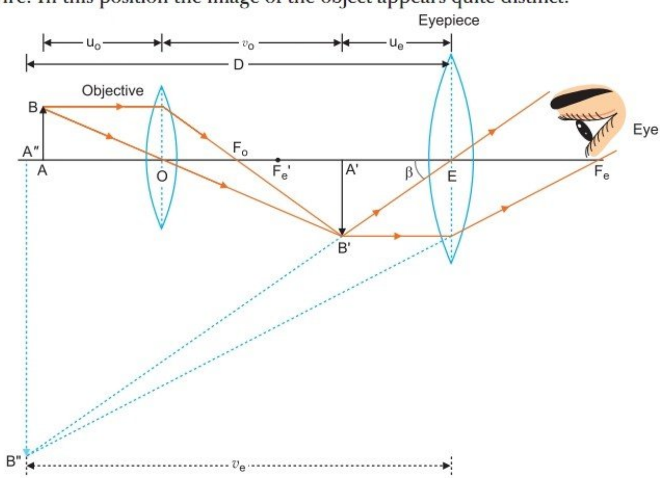
Why both objective and eyepiece of a compound microscope must have short focal lengths?

(b) **Draw a ray diagram showing the image formation by a compound microscope. Hence obtain expression for total magnification when the image is formed at infinity.**

[*CBSE Delhi 2013*]

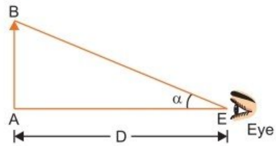
Ans. *(a)* **Compound Microscope:** It consists of a long cylindrical tube, containing at one end a convex lens of small aperture and small focal length. This is called the objective lens *(O)*. At the other end of the tube another co-axial smaller and wide tube is fitted, which carries a convex lens *(E)* at its outer end. This lens is towards the eye and is called the eye-piece. The focal length and aperture of eyepiece are somewhat larger than those of objective lens. Cross-wires are mounted at a definite distance before the eyepiece. The entire tube can be moved forward and backward by the rack and pinion arrangement.

Adjustment: First of all the eyepiece is displaced backward and forward to focus it on cross-wires. Now the object is placed just in front of the objective lens and the entire tube is moved by rack and pinion arrangement until there is no parallax between image of object and cross wire. In this position the image of the object appears quite distinct.



Working : Suppose a small object AB is placed slightly away from the first focus F_0' of the objective lens. The objective lens forms the real, inverted and magnified image $A'B'$ which acts as an object for eyepiece. The eyepiece is so adjusted that the image $A'B'$ lies between the first focus F_e' and the eyepiece E. The eyepiece forms its image $A''B''$ which is virtual, erect and magnified. Thus the final image $A''B''$ formed by the microscope is inverted and magnified and its position is outside the objective and eyepiece towards objective lens.

Magnifying power of a microscope is defined as the ratio of angle (β) subtended by final image on the eye to the angle (α) subtended by the object on eye, when the object is placed at the least distance of distinct vision, *i.e.*,



Magnifying power $M = \dfrac{\beta}{\alpha}$.

As object is very small, angles α and β are very small and so $\tan\alpha = \alpha$ and $\tan\beta = \beta$. By definition the object AB is placed at the least distance of distinct vision.

$$\alpha = \tan\alpha = \frac{AB}{EA}$$

By sign convention $\quad EA = -D, \qquad \therefore \quad \alpha = \dfrac{AB}{-D}$

and from figure $\qquad \beta = \tan\beta = \dfrac{A'B'}{EA'}$

If u_e is distance of image $A'B'$ from eye-piece E, then by sign convention, $EA' = -u_e$

and so, $\qquad \beta = \dfrac{A'B'}{(-u_e)}$

Hence magnifying power $M = \dfrac{\beta}{\alpha} = \dfrac{A'B'/(-u_e)}{AB/(-D)} = \dfrac{A'B'}{AB}\cdot\dfrac{D}{u_e}$

By sign conventions, magnification of objective lens

$$\frac{A'B'}{AB} = \frac{v_0}{(-u_0)}$$

$$M = -\frac{v_0}{u_0}\cdot\frac{D}{u_e}$$

Using lens formula $\dfrac{1}{f} = \dfrac{1}{v} - \dfrac{1}{u}$ for eye-lens, (*i.e.*, using $f = f_e$, $v = v_e$, $u = -u_e$), we get

$$\frac{1}{f_e} = \frac{1}{-v_e} - \frac{1}{(-u_e)} \quad \text{or} \quad \frac{1}{u_e} = \frac{1}{f_e} + \frac{1}{v_e}$$

Magnifying power $\quad M = -\dfrac{v_0}{u_0}D\left(\dfrac{1}{f_e} + \dfrac{1}{v_e}\right)$

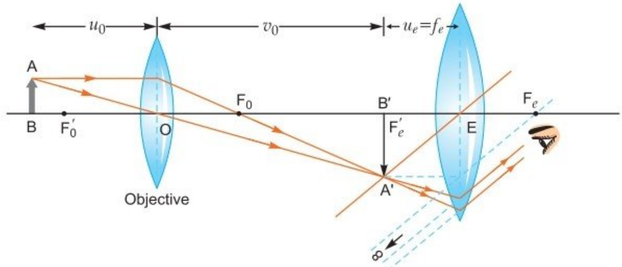
or $\qquad M = -\dfrac{v_0}{u_0}\left(\dfrac{D}{f_e} + \dfrac{D}{v_e}\right)$

When final image is formed at the distance of distinct vision, $v_e = D$

$$\text{Magnification, } M = -\frac{v_0}{u_0}\left(1 + \frac{D}{f_e}\right)$$

For greater magnification of a compound microscope, f_e should be small. As $f_0 < fe$, so f_0 is small. Hence, for greater magnification both f_0 and f_e should be small with f_0 to be smaller of the two.

(*b*) If image $A'B'$ is exactly at the focus of the eyepiece, then image $A''B''$ is formed at infinity.



If the object AB is very close to the focus of the objective lens of focal length f_o, then magnification M_o by the objective lens

$$M_o = \frac{L}{f_0}$$

where L is tube length (or distance between lenses L_o and L_e)

Magnification M_e by the eyepiece

$$M_e = \frac{D}{f_e}$$

where D = Least distance of distinct vision

Total magnification, $m = M_o M_e = \left(\frac{L}{f_o}\right)\left(\frac{D}{f_e}\right)$

Q. 9. Explain with the help of a labelled ray diagram, how is image formed in an astronomical telescope. Derive an expression for its magnifying power.

[*CBSE (F) 2014, 2019 (55/1/1) 2020 (55/1/1), 2023 (55/4/1)*]

OR

Draw a ray diagram showing the image formation of a distant object by a refracting telescope. Define its magnifying power and write the two important factors considered to increase the magnifying power.

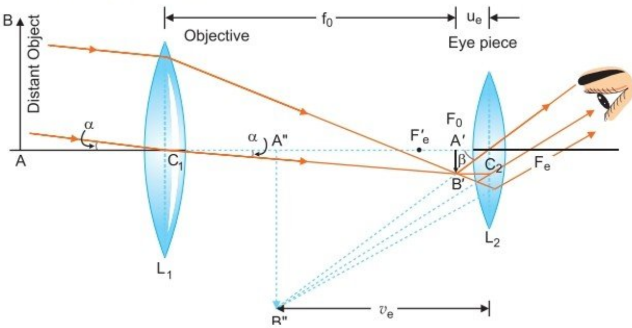
Describe briefly the two main limitations and explain how far these can be minimised in a reflecting telescope. **[*CBSE (F) 2015, 2023 (55/2/1)*]**

Ans. Astronomical (Refracting) Telescope:

Construction: It consists of two co-axial cylindrical tubes, out of which one tube is long and wide, while the other tube is small and narrow. The narrow tube may be moved in and out of the wide tube by rack and pinion arrangement. At one end of wide tube an achromatic convex lens L_1 is placed, which faces the object and is so called ***objective (lens)***. The focal length and aperture of this lens are kept large. The large aperture of objective is taken that it may collect sufficient light to form a bright image of a distant object. The narrow tube is towards eye and carries an achromatic convex lens L_2 of small focal length and small aperture on its outer end. This is called **eye-lens or eyepiece.** The small aperture of eye-lens is taken so that the whole light refracted by it may reach the eye. Cross-wires are fitted at a definite distance from the eye-lens.

Due to large focal length of objective lens and small focal length of eye lens, the final image subtends a large angle at the eye and hence the object appears large. The distance between the two lenses may be arranged by displacing narrow tube in or out of wide tube by means of rack and pinion arrangement.

Adjustment: First of all the eyepiece is moved backward and forward in the narrow tube and focused on the cross-wires. Then the objective lens is directed towards the object and narrow tube is displaced in or out of wide tube until the image of object is formed on cross-wires and there is no parallax between the image and cross-wires. In this position a clear image of the object is seen. As the image is formed by refraction of light through both the lenses, this telescope is called the ***refracting telescope.***



Working: Suppose AB is an object whose end A is on the axis of telescope. The objective lens (L_1) forms the image $A'B'$ of the object AB at its second principal focus F_0 This image is real, inverted and diminished. This image $A'B'$ acts as an object for the eye-piece L_2 and lies between first focus F_e and optical centre C_2 of lens L_2. Therefore eye-piece forms its image $A''B''$ which is virtual, erect and magnified.

Thus the final image $A''B''$ of object AB formed by the telescope is magnified, inverted and lies between objective and eyepiece.

Magnifying Power: The magnifying power of a telescope is measured by the ratio of angle (β) subtended by final image on the eye to the angle (α) subtended by object on the eye, *i.e.*,

Magnifying power $M = \dfrac{\beta}{\alpha}$

As α and β are very small angles, therefore, from figure.

The angle subtended by final image $A''B''$ on eye

β = angle subtended by image $A'B'$ on eye

$$= \tan\beta = \frac{A'B'}{C_2A'}$$

As the object is very far (at infinity) from the telescope, the angle subtended by object at eye is same as the angle subtended by object on objective lens.

$$\alpha = \tan\alpha = \frac{A'B'}{C_1A'}$$

$$M = \frac{\beta}{\alpha} = \frac{A'B'/C_2A'}{A'B'/C_1A'} = \frac{C_1A'}{C_2A'}$$

If the focal lengths of objective and eye-piece be f_o, and f_e, distance of image $A'B'$ from eye-piece be u_e, then by sign convention

$$C_1A' = +f_0\,,\; C_2A' = -u_e$$

$$M = -\frac{f_0}{u_e}$$

If v_e is the distance of $A''B''$ from eye-piece, then by sign convention, f_e is positive, u_e and v_e both are negative. Hence by lens formula $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$, we have

$$\frac{1}{f_e} = \frac{1}{-v_e} - \frac{1}{(-u_e)} \text{ or } \frac{1}{u_e} = \frac{1}{f_e} + \frac{1}{v_e}$$

Substituting this value in (*i*), we get

$$M = -f_0\left(\frac{1}{f_e} + \frac{1}{v_e}\right)$$

This is the general formula for magnifying power. In this formula only numerical values of f_0, f_e and v_e are to be used because signs have already been used.

Length of Telescope: The distance between objective and eye-piece is called the length (L) of the telescope. Obviously

$$L = L_1L_2 = C_1C_2 = f_o + u_e$$

Now there arise two cases:

(*i*) **When the final image is formed at minimum distance (D) of distinct vision :** then $v_e = D$

$$M = -f_0\left(\frac{1}{f_e} + \frac{1}{D}\right) = -\frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right)$$

Length of telescope $L = f_o + u_e$

(*ii*) **In normal adjustment position, the final image is formed at infinity :** For relaxed eye, the final image is formed at infinity. In this state, the image $A'B'$ formed by objective lens should be at first the principal focus of eyepiece, *i.e.*,

$$u_e = f_o \text{ and } v_e = \infty$$

$\therefore$ Magnifying power, $M = -f_o\left(\frac{1}{f_e} + \frac{1}{\infty}\right) = -\frac{f_o}{f_e}$

Length of telescope $= f_0 + f_e$.

For large magnifying power, f_o should be large and f_e should be small.

For high resolution of the telescope, diameter of the objective should be large.

Factors for increasing the magnifying power

1. Increasing focal length of objective
2. Decreasing focal length of eye piece

Limitations

1. Suffers from chromatic aberration
2. Suffers from spherical aberration
3. Small magnifying power
4. Small resolving power

Q. 10. (*i*) Draw a labelled ray diagram to obtain the real image formed by an astronomical telescope in normal adjustment position. Define its magnifying power.

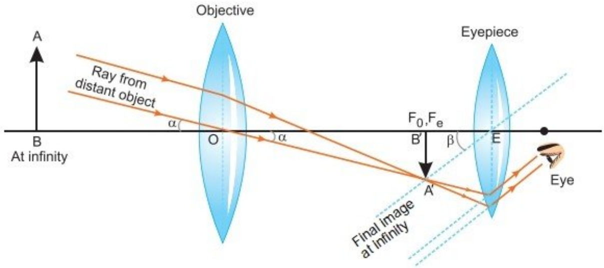
[*CBSE Sample paper-2022, Term-2*] [*CBSE 2019 (55/1/2)*]

(*ii*) You are given three lenses of power 0.5 D, 4 D and 10 D to design a telescope.

(*a*) Which lenses should be used as objective and eyepiece? Justify your answer.

(*b*) Why is the aperture of the objective preferred to be large? [*CBSE (Central) 2016*]

Ans. (*i*)



Definition: It is the ratio of the angle (β) subtended at the eye by the final image, to the angle (α) subtended by the object on the eye, *i.e.*, $M = \dfrac{\beta}{\alpha}$

(*ii*) (*a*) Objective = 0.5 D

Eye lens = 10 D

This choice would give higher magnification as

$$M = \frac{f_0}{f_e} = \frac{P_e}{P_0}$$

(*b*) The aperture of the objective lens is preferred to be large that it may collect sufficient light to form a brighter image of a distant object.

Q. 11. (*a*) State two main considerations taken into account while choosing the objective of astronomical telescope.

(*b*) Draw a ray diagram of reflecting type telescope. State its magnifying power.

(*c*) State the advantages of reflecting type telescope over the refracting type.

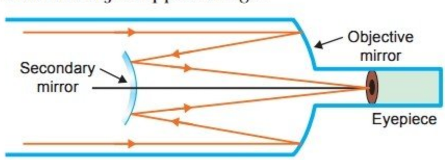
[*CBSE Sample Paper 2021*]

Ans. (*a*) The main considerations taken into account while choosing the objective of astronomical telescope is:

(*i*) The aperture of objective lens is kept large so, that it may collect sufficient light to form a bright image of a distant object.

(*ii*) The focal length of objective is kept large so that the final image subtends a large angle at the eye and the object appears large.

(*b*)



If f_0 and f_e are the focal lengths of objective and eyepiece respectively, then magnifying power when the image is formed at the least distance of distinct vision,

$$m = \frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right)$$

Magnifying power when image is formed at infinity,

$$m = \frac{f_0}{f_e}$$

(*c*) The advantages of reflecting type telescope over refractive type telescope:

(*i*) No chromatic aberration, because mirror is used.

(*ii*) Easy mechanical support (less mechanical support is required, because mirror weighs much less than a lens of equivalent optical quality)

(*iii*) Large gathering power

(*iv*) Large magnifying power

(*v*) Large resolving power

(*vi*) Spherical aberration can be removed by using parabolic mirror

Q. 12. Draw a graph to show the angle of deviation δ with the variation of angle of incidence i for a monochromatic ray of light passing through a prism of refracting angle A. Deduce the relation

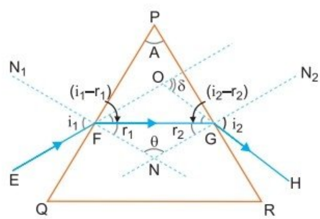
$$n = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

[*CBSE Delhi 2011, 2016; (F) 2011, 2017; Sample Paper 2016, 2020(55/4/1)*]

OR

Draw a ray diagram showing refraction of a ray of light through a triangular glass prism. Hence, obtain the relation for the refractive index (μ) in terms of angle of prism (A) and angle of minimum deviation (δ_m). **[*CBSE 2023(55/3/1)*]**

Ans. Graph of deviation in δ with variation in angle of incidence i : The homogeneous transparent medium (such as glass) enclosed by two plane refracting surfaces is called a prism. The angle between the refracting surfaces is called the refracting angle or angle of prism. The section cut by a plane perpendicular to the refracting surfaces is called the principal section of the prism.



Let PQR be the principal section of the prism. The refracting angle of the prism is A.

A ray of monochromatic light EF is incident on face PQ at angle of incidence i_1 The refractive index of material of prism for this ray is n. This ray enters from rarer to denser medium and so is deviated towards the normal FN_1 and gets refracted along the direction FG. The angle of refraction for this face is r_1 The refracted ray FG becomes incident on face PR and is refracted away from the normal GN_2 and emerges in the direction GH. The angle of incidence on this face is r_2 (into prism) and angle of refraction (into air) is i_2. The incident ray EF and emergent ray GH when produced meet at O. The angle between these two rays is called angle of deviation 'δ'.

$$\angle OFG = i_1 - r_1 \quad \text{and} \quad \angle OGF = i_2 - r_2$$

In $\Delta\, FOG$, δ is exterior angle

$$\delta = \angle\, OFG + \angle OGF = (i_1 - r_1) + (i_2 - r_2)$$

$$= (i_1 + i_2) - (r_1 + r_2) \qquad ...(i)$$

The normals FN_1 and GN_2 on faces PQ and PR respectively, when produced meet at N. Let $\angle FNG = \theta$ In $\Delta\, FGN$, $\quad r_1 + r_2 + \theta = 180°$ ...(ii)

In quadrilateral $PFNG$, $\angle\, PFN = 90°$, $\angle\, PGN = 90°$

$$A + 90° + \theta + 90° = 360° \text{ or } A + \theta = 180° \qquad ...(iii)$$

Comparing (ii) and (iii), $\quad r_1 + r_2 = A$ ...(iv)

Substituting this value in (i), we get

$$\delta = i_1 + i_2 - A \qquad ...(v)$$

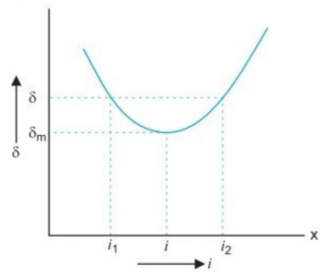
or

$$i_1 + i_2 = A + \delta \qquad ...(vi)$$

From Snell's law, $n = \dfrac{\sin i_1}{\sin r_1} = \dfrac{\sin i_2}{\sin r_2}$ ...(vii)

Minimum Deviation: From equation (v), it is clear that the angle of deviation depends upon the angle of incidence i_1 As the path of light is reversible, therefore if angle of incidence be i_2 then angle of emergence will be i_1 Thus for two angles of incidence

i_1 and i_2 there will be one angle of deviation.



If we determine experimentally, the angles of deviation corresponding to different angles of incidence and then plot i (*on* X-axis) and δ (on Y-axis), we get a curve as shown in figure. Clearly if angle of incidence is gradually increased, from a small value, the angle of deviation first decreases, becomes minimum for a particular angle of incidence and then begins to increase. Obviously for one angle of deviation (δ) there are two angles of incidences i_1 and i_2 , but ***for one and only one particular value of angle of incidence (i), the angle of deviation is the minimum.*** This minimum angle of deviation is represented by δ_m. For minimum deviation i_1 and i_2 become coincident, *i.e.*,$i_1 = i_2 = i$ (say)

So from (vii) $\quad r_1 = r_2 = r$ (say)

Hence from (iv) and (vi), we get $\quad r + r = A \Rightarrow r = A / 2$

and

$$i + i = A + \delta_m \text{or } i = \frac{A + \delta_m}{2}$$

Hence, from Snell's law, $n = \dfrac{\sin i}{\sin r} = \dfrac{\sin\left(\dfrac{A + \delta_m}{2}\right)}{\sin\left(\dfrac{A}{2}\right)}$

Questions for Practice

1. Choose and write the correct option in the following questions.

(*i*) An astronomical telescope has objective and eyepiece of focal length 40 cm and 4 cm respectively. To view an object 200 cm away from the objective, the lenses must be separated by a distance

(*a*) 50.0 cm (*b*) 54.0 cm (*c*) 37.3 cm (*d*) 46.0

(*ii*) The angle of incidence for a ray of light at a refracting surface of a prism is 45°. The angle of prism is 60°. If they ray suffers minimum deviation through the prism, the angle of minimum deviation and refractive index of the material of the prism respectively, are.

(*a*) $45°; \sqrt{2}$ (*b*) $30°; \frac{1}{\sqrt{2}}$ (*c*) $45°; \frac{1}{\sqrt{2}}$ (*d*) $30°; \sqrt{2}$

(*iii*) Why is refractive index in a transparent medium greater than one?

(*a*) Because the speed of light in vacuum is always less than speed in a transparent medium

(*b*) Because the speed of light in vacuum is always greater than the speed in a transparent medium

(*c*) Frequency of wave changes when it crosses medium

(*d*) None of the above

(*iv*) Light wave enters from medium 1 to medium 2. Its velocity in 2nd medium is double from 1st. For total internal reflection the angle of incidence must be greater than

(*a*) 30° (*b*) 60° (*c*) 45° (*d*) 90°

(*v*) A thin glass (refractive index 1.5) lens has optical power of – 5 D in air. Its optical power in a liquid medium with refractive index 1.6 will be

(*a*) 1 D (*b*) –1 D (*c*) 25 D (*d*) 0.625 D

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

(a) ***Both A and R are true and R is the correct explanation of A.***

(b) ***Both A and R are true but R is not the correct explanation of A.***

(c) ***A is true but R is false.***

(d) ***A is false and R is also false.***

Assertion(*A*) : If a convex lens is kept in water, its convergence power decreases.

Reason (*R*) : The refractive index of convex lens relative to water is less than that relative to air.

3. A biconvex lens made of a transparent material of refractive index 1.25 is immersed in water of refractive index 1.33. Will the lens behave as a converging lens? Give reason.

4. How does the angle of minimum deviation of a glass prism vary, if the incident violet light is replaced by red light? Give reason.

5. (*a*) State the conditions for total internal reflection to take place.

(*b*) Suspended by a thread in the liquid is gradually lowered till it touches the bottom. The apparent depth is determined corresponding to different positions of the coin.

(*i*) Plot a graph showing variation of the apparent depth with the real depth of the coin.

(*ii*) What is the physical significance of the slope of the graph? ***[CBSE 2022 (55/2/1), Term-2]***

6. For the same angle of incidence the angles of refraction in three different media *A*, *B* and *C* are 15°, 25° and 35° respectively. In which medium the velocity of light is minimum?

7. Two monochromatic rays of light are incident normally on the face *AB* of an isosceles right-angled prism *ABC*. The refractive indices of the glass prism for the two rays '1' and '2' are respectively 1.3 and 1.5. Trace the path of these rays after entering through the prism. Explain briefly.

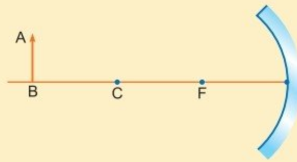
8. The radii of curvature of the two surfaces of a concave lens are 20 cm each. Find the refractive index of the material of the lens if its power is –5.0 D. ***[CBSE 2023 (55/3/1)]***

9. A biconvex lens has a focal length $\frac{2}{3}$ times the radius of curvature of either surface. Calculate the refractive index of lens material.

10. Light from a point source in air falls on a convex spherical glass surface of refractive index 1.5 and radius of curvature 20 cm. The distance of light source from the glass surface is 100 cm. At what position is the image formed?

11. A 1.8 m tall person stands in front of a convex lens of focal length 1 m, at a distance of 5 m. Find the position and height of the image formed. *[CBSE 2023 (55/3/1)]*

12. An object *AB* is kept in front of a concave mirror as shown in the figure. *[CBSE (AI) 2012]*



(*i*) Complete the ray diagram showing the image formation of the object.

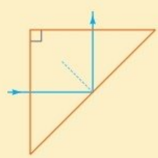
(*ii*) How will the position and intensity of the image be affected if the lower half of the mirror's reflecting surface is painted black?

13. A converging and a diverging lens of equal focal lengths are placed co-axially in contact. Find the power and the focal length of the combination. *[CBSE (AI) 2010]*

14. An object is kept in front of a concave mirror of focal length 15 cm. The image formed is real and three times the size of the object. Calculate the distance of the object from the mirror. *[CBSE 2019 (55/4/1)]*

15. The radii of curvature of both the surfaces of a lens are equal. If one of the surfaces is made plane by grinding, then will the focal length of lens change? Will the power change? *[CBSE Guwahati 2015]*

16. A ray of light incident normally on one face of a right isosceles prism is totally reflected as shown in figure. What must be minimum value of refractive index glass? Give relevant calculations. *[CBSE Delhi 2016]*



17. A small bulb is placed at the bottom of a tank containing water to a depth of 80 cm. What is the area of the surface of water through which light from the bulb can emerge out? Refractive index of water is $\frac{4}{3}$. *[NCERT]*

18. How is the working of a telescope different from that of a microscope? *[CBSE Delhi 2012, 2019 (55/2/3)]*

19. A double convex lens is made of a glass of refractive index 1.55, with both faces of the same radius of curvature. Find the radius of curvature required, if the focal length is 20 cm. *[CBSE (AI) 2017]*

20. Draw a ray diagram to show the image formation of a distant object by a refracting telescope. Write the expression for its angular magnification in terms of the focal lengths of the lenses used. State the important considerations required to achieve large resolution and their consequent limitations.

21. (*a*) Plot a graph for angle of deviation as a function of angle of incidence for a triangular prism.

(*b*) Derive the relation for the refractive index of the prism in terms of the angle of minimum deviation and angle of prism.

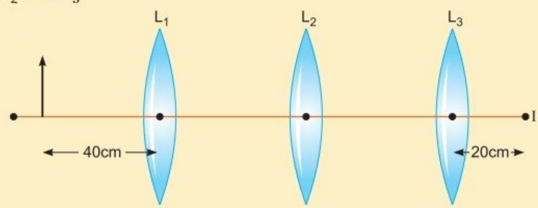
22. An optical instrument uses a lens of 100 D for the objective lens and 50 D for its eye piece. When the tube length is kept at 20 cm, the final image is formed at infinity.

(*a*) Identify the optical instrument.

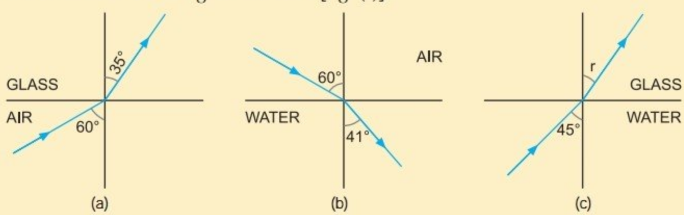
(*b*) Calculate the magnification produced by the instrument. **[*CBSE 2020 (55/5/1)*]**

23. Two objects P and Q when placed at different positions in front of a concave mirror of focal length 20 cm, form real images of equal size. Size of object P is three times size of object Q. If the distance of P is 50 cm from the mirror, find the distance of Q from the mirror. **[*CBSE 2020 (55/4/1)*]**

24. You are given three lenses L_1, L_2 and L_3 each of focal length 20 cm. An object is kept at 40 cm in front of L_1, as shown. The final real image is formed at the focus 'I' of L_3. Find the separations between L_1, L_2 and L_3. **[*CBSE (AI) 2012*]**



25. Fig. (*a*) and (*b*) show refraction of an incident ray in air at 60° with the normal to a glass-air and water-air interface, respectively. Predict the angle (r) of refraction of an incident ray in water at 45° with the normal to a water-glass interface [fig. (*c*)]. **[*NCERT*]**



26. An angular magnification of 30X is desired using an objective of focal length 1.25 cm and an eye-piece of focal length 5 cm. How would you set up the compound microscope?

[*NCERT*] [*CBSE Sample Paper 2018*]

27. A small telescope has an objective lens of focal length 144 cm and an eye piece of focal length 6.0 cm. What is the magnifying power of the telescope? What is the separation between the objective and the eye-piece? **[*NCERT*]**

28. An object of size 3.0 cm is placed 14 cm in front of a concave lens of focal length 21 cm. Describe the image produced by the lens. What happens if the object is moved farther from the lens? **[*NCERT*]**

29. (*a*) Calculate the distance of an object of height h from a concave mirror of radius of curvature 20 cm, so as to obtain a real image of magnification 2. Find the location of image also.

(*b*) Using mirror formula, explain why does a convex mirror always produce a virtual image.

[*CBSE Delhi 2016*]

30. (*a*) A mobile phone lies along the principal axis of a concave mirror. Show, with the help of a suitable diagram, the formation of its image. Explain why magnification is not uniform.

(*b*) Suppose the lower half of the concave mirror's reflecting surface is covered with an opaque material. What effect this will have on the image of the object? Explain. **[*CBSE Delhi 2014*]**

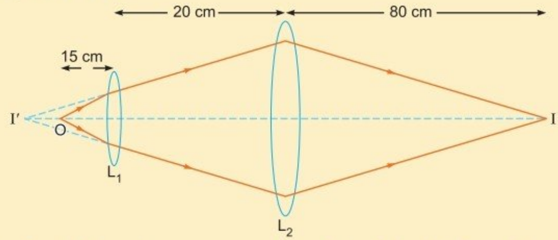
31. A convex lens made up of glass of refractive index 1.5 is dipped, in turn, in (*i*) a medium of refractive index 1.65, (*ii*) a medium of refractive index 1.33.

(*a*) Will it behave as a converging or a diverging lens in the two cases?

(*b*) How will its focal length change in the two media? **[*CBSE (AI) 2011*]**

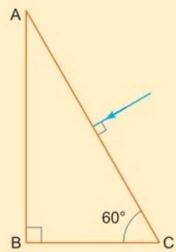
32. A converging lens has a focal length of 20 cm in air. It is made of a material of refractive index 1.6. If it is immersed in a liquid of refractive index 1.3, find its new focal length. **[*CBSE (F) 2017*]**

33. In the following diagram, an object 'O' is placed 15 cm in front of a convex lens L_1 of focal length 20 cm and the final image is formed at 'I' at a distance of 80 cm from the second lens L_2. Find the focal length of the L_2. **[*CBSE (F) 2016*]**



34. An object is placed 40 cm from a convex lens of focal length 30 cm. If a concave lens of focal length 50 cm is introduced between the convex lens and the image formed such that it is 20 cm from the convex lens, find the change in the position of the image. **[*CBSE Chennai 2015*] [*HOTS*]**

35. Trace the path of a ray of light passing through a glass prism (ABC) as shown in the figure. If the refractive index of glass is $\sqrt{3}$, find out of the value of the angle of emergence from the prism. **[*CBSE (F) 2012*] [*HOTS*]**



Answers

1. (*i*) (*b*)	(*ii*) (*d*)	(*iii*) (*b*)	(*iv*) (*a*)	(*v*) (*d*)	
2. (*a*)	**8.** $\frac{3}{2}$	**9.** $\frac{7}{4}$	**10.** 100 cm	**11.** 1.25 m, – 0.45 m	
13. infinite	**14.** –20 cm	**16.** $\sqrt{2}$	**17.** 2.6 m^2	**19.** 22 cm	**22.** (*b*) 312.5
23. – 30 cm	**24.** 60 cm (between L_2 and L_3)				
25. (*a*) 1.51 (*b*) 1.32 (*c*) 38°	**26.** 11.67	**27.** –24, 150 cm			**28.** –8.4 cm, 1.8 cm
29. (*a*) –15 cm, –30 cm	**32.** 52 cm	**33.** – 40 cm	**34.** 200 cm	**35.** 60°	

10 Wave Optics

POINTS TO REMEMBER

1. Wave Nature of Light: Huygen's Theory

There are some phenomena like interference, diffraction and polarisation which could not be explained by Newton's corpuscular theory. These were explained by wave theory first proposed by Huygen.

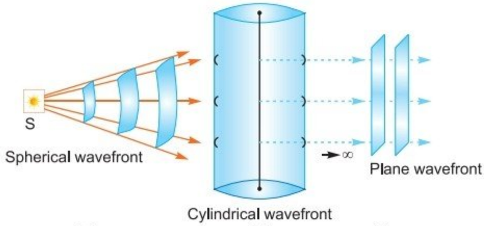
The assumptions of Huygen's wave theory are: (*i*) A source sends waves in all possible directions. The locus of particles of a medium vibrating in the same phase is called a **wavefront**. For a point source, the wavefront is spherical; while for a line source the wavefront is cylindrical. A distant wavefront is plane. (*ii*) Each point of a wavefront acts as a source of secondary wavelets. The envelope of all wavelets at a given instant gives the position of a new wavefront.

2. Wavefront

A wavefront is defined as the locus of all the particles which are vibrating in the same phase. The perpendicular line drawn at any point on the wavefront represents the direction of propagation of the wave at that point and is called the '**ray**'.

Types of Wavefronts: The wavefronts can be of different shapes. In general, we experience three types of wavefronts.

(*i*) **Spherical Wavefront:** If the waves in a medium are originating from a point source, then they propagate in all directions. If we draw a spherical surface centred at point-source, then all the particles of the medium lying on that spherical surface will be in the same phase, because the disturbance starting from the source will reach all these points simultaneously. Hence in this case, the wavefront will be spherical and the rays will be the radial lines [Fig (*a*)].



(a) (b) (c)

(*ii*) **Cylindrical Wavefront:** If the waves in a medium are originating from a line source, then they too propagate in all directions. In this case the locus of particles vibrating in the same phase will be a cylindrical surface. Hence in this case the wavefront will be cylindrical. [Fig. (*b*)] (*iii*) **Plane Wavefront:** At large distance from the source, the radii of spherical or cylindrical wavefront will be too large and a small part of the wavefront will appear to be plane. At infinite distance from the source, the wavefronts are always plane and the rays are parallel straight lines.

The equation $y = a \sin 2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)$

represents the plane wave propagating along positive direction of X-axis.

3. Coherent and Incoherent Sources of Light

The sources of light emitting waves of same frequency having zero or constant initial phase difference are called coherent sources.

The sources of light emitting waves with a random phase difference are called incoherent sources. For interference phenomenon, the sources must be coherent.

Methods of Producing Coherent Sources: Two independent sources can never be coherent sources. There are two broad ways of producing coherent sources for the same source.

(*i*) **By division of wavefront:** In this method the wavefront (which is the locus of points of same phase) is divided into two parts. The examples are Young's double slit and Fresnel's biprism.

(*ii*) **By division of amplitude:** In this method the amplitude of a wave is divided into two parts by successive reflections, *e.g.*, Lloyd's single mirror method.

4. Interference of Light

Interference is the phenomenon of superposition of two light waves of same frequency and constant phase different travelling in same direction. The positions of maximum intensity are called *maxima*, while those of minimum intensity are called *minima*.

Conditions of Maxima and Minima: If a_1 and a_2 are amplitudes of interfering waves and ϕ is the phase difference at a point under consideration, then

Resultant intensity at a point in the region of superposition

$$I = a_1^2 + a_2^2 + 2a_1 a_2 \cos\phi$$
$$= I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$$

where $I_1 = a_1^2$ = intensity of one wave

$I_2 = a_2^2$ = intensity of other wave

Condition of Maxima:

Phase difference, $\phi = 2n\pi$

or path difference, $\Delta = n\lambda$, n being integer

Maximum amplitude, $A_{\max} = a_1 + a_2$

Maximum intensity, $I_{\max} = A^2_{\max} = (a_1 + a_2)^2$

$$= a_1^2 + a_2^2 + 2a_1 a_2 = I_1 + I_2 + 2\sqrt{I_1 I_2}$$

Condition of Minima: Phase difference, $\phi = (2n - 1)\pi$

Path difference, $\Delta = (2n-1)\frac{\lambda}{2}, n = 1, 2, 3, ...$

Minimum amplitude, $A_{\min} = (a_1 - a_2)$

Minimum intensity, $I_{\min} = (a_1 - a_2)^2 = a_1^2 + a_2^2 - 2a_1 a_2$

$$= I_1 + I_2 - 2\sqrt{I_1 I_2}$$

Young's Double Slit Experiment

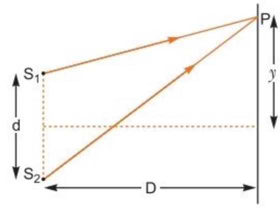
Let S_1 and S_2 be coherent sources at separation d and D be the distance of screen from sources, then path difference between waves reaching at P can be shown as

$$\Delta = \frac{y_n d}{D}$$

For maxima $\Delta = n\lambda$

$\therefore$ Position of nth maxima $y_n = \frac{nD\lambda}{d}$

$\therefore$ Position of nth minima $y_n = \left(n - \frac{1}{2}\right)\frac{D\lambda}{d}$



Fringe width: Fringe width is defined as the separation between two consecutive maxima or minima.

Linear fringe width, $\beta = y_{-n+1} - y_n = \frac{D\lambda}{d}$

Angular fringe width, $\beta_\theta = \frac{\beta}{D} = \frac{\lambda}{d}$.

Use of white light: When white light is used to illuminate the slit, we obtain an interference pattern consisting of a central white fringe having few coloured fringes on two sides and uniform illumination.

Remark: If waves are of same intensity,

$$I_1 = I_2 = I_0 \text{ (say) then}$$
$$I = 2I_0 + 2I_0 \cos\phi$$
$$= 2I_0(1 + \cos\phi)$$
$$= 4I_0 \cos^2\frac{\phi}{2}$$

5. Diffraction of Light

The bending of light from the corner of small obstacles or apertures is called diffraction of light.

Diffraction due to a Single Slit:

When a parallel beam of light is incident normally on a single slit, the beam is diffracted from the slit and the diffraction pattern consists of a very intense central maximum, and secondary maxima and minima on either side alternately.

If a is width of slit and θ the angle of diffraction, then the directions of maxima are given by

$$a\sin\theta = \left(n + \frac{1}{2}\right)\lambda \qquad n = 1, 2, 3, \ldots$$

The position of nth minima are given by

$$a \sin\theta = n\lambda,$$

where $n = \pm 1, \pm 2, \pm 3, \ldots$ for various minima on either side of principal maxima.

Width of Central Maximum:

The width of central maximum is the separation between the first minima on either side.

The condition of minima is

$$a \sin\theta = \pm n\lambda \; (n = 1, 2, 3, \ldots).$$

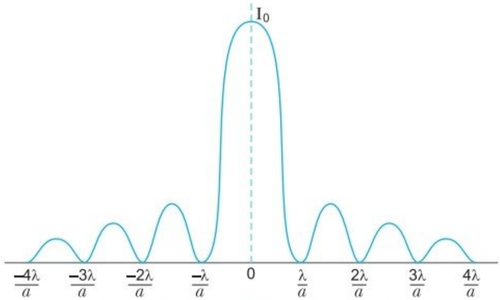
The angular position of the first minimum ($n=1$) on either side of central maximum is given by

$$a \sin\theta = \pm\lambda$$

$$\Rightarrow \qquad \theta = \pm\sin^{-1}\left(\frac{\lambda}{a}\right)$$

$\therefore$ Half-width of central maximum, $\theta = \sin^{-1}\left(\frac{\lambda}{a}\right)$

$\therefore$ Total width of central maximum, $\beta = 2\theta = 2\sin^{-1}\left(\frac{\lambda}{a}\right)$



Diffraction due to a single slit by a monochromatic light

Linear Width: If D is the distance of the screen from slit and y is the distance of nth minima from the centre of the principal maxima, then

$$\sin\theta \simeq \tan\theta \simeq \theta = \frac{y}{D}$$

Now, $$n\lambda = a\sin\theta \simeq a\,\theta$$

$$\theta = \frac{\lambda n}{a} = \frac{y_n}{D}$$

$\Rightarrow$ $$y_n = \frac{n\lambda D}{a}$$

Linear half-width of central maximum, $y = \frac{\lambda D}{a}$

Total linear width of central maximum, $\beta = 2y = \frac{2\lambda D}{a}$

Multiple Choice Questions

Choose and write the correct option(s) in the following questions.

1. **When a wave undergoes reflection at an interface from rarer to denser medium, adhoc change in its phase is** [*CBSE 2020 (55/4/1)*]

   (*a*) $\frac{\pi}{2}$ (*b*) 0 (*c*) π (*d*) $\frac{\pi}{4}$

2. **Two waves having the intensities in the ratio of 9 : 1 produce interference. The ratio of maximum to minimum intensity is**

   (*a*) 10 : 8 (*b*) 9 : 1 (*c*) 4 : 1 (*d*) 2 : 1

3. **Four independent waves are expressed as**

   (*i*) $y_1 = a_1\sin\omega t$ **(*ii*) $y_2 = a_2\sin 2\omega t$**

   (*iii*) $y_3 = a_3\cos\omega t$ and **(*iv*) $y_4 = a_4\sin(\omega t + \pi/3)$**

   The interference is possible between

   (*a*) (*i*) and (*iii*) (*b*) (*i*) and (*iv*)

   (*c*) (*iii*) and (*iv*) (*d*) not possible at all

4. **Consider sunlight incident on a slit of width 10^4 A. The image seen through the slit shall** **[*NCERT Exemplar*]**

(*a*) be a fine sharp slit white in colour at the center.

(*b*) a bright slit white at the center diffusing to zero intensities at the edges.

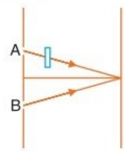
(*c*) a bright slit white at the center diffusing to regions of different colours.

(*d*) only be a diffused slit white in colour.

5. **In a Young's double-slit experiment the fringe width is found to be 0.4 mm. If the whole apparatus is dipped in water of refractive index 4/3, without disturbing the arrangement, the new fringe width will be**

(*a*) 0.30 mm (*b*) 0.40 mm (*c*) 0.53 mm (*d*) 0.2 mm

6 **In Young's experiment, monochromatic light is used to illuminate the slits *A* and *B*. Interference fringes are observed on a screen placed in front of the slits. Now if a thin glass plate is placed in the path of the beam coming from A, then**



(*a*) the fringes will disappear

(*b*) the fringe width will increase

(*c*) the fringe width will decrease

(*d*) there will be no change in the fringe width

7. **In Young's double slit experiment the separation *d* between the slits is 2 mm, the wavelength λ of the light used is 5896 Å and distance *D* between the screen and slits is 100 cm. It is found that the angular width of the fringes is 0.20°. To increase the fringe angular width to 0.21° (with same λ and *D*) the separation between the slits needs to be changed to**

(*a*) 1.8 mm

(*b*) 1.9 mm

(*c*) 2.1 mm

(*d*) 1.7 mm

8. **In a Young's double slit experiment, the source is white light. One of the holes is covered by a red filter and another by a blue filter. In this case** **[*NCERT Exemplar*]**

(*a*) there shall be alternate interference patterns of red and blue.

(*b*) there shall be an interference pattern for red distinct from that for blue.

(*c*) there shall be no interference fringes.

(*d*) there shall be an interference pattern for red mixing with one for blue.

9. **In a Young's double-slit experiment, the source *S* and two slits *A* and *B* are horizontal, with slit *A* above slit *B*. The fringes are observed on a vertical screen *K*. The optical path length from *S* to *B* is increased very slightly (by introducing a transparent material of higher refractive index) and optical path length from *S* to *A* is not changed. As a result, the fringe system on *K* moves**

(*a*) vertically downwards slightly

(*b*) vertically upwards slightly

(*c*) horizontally slightly to the left

(*d*) horizontally slightly to the right

10. **In Young's double-slit experiment, the distance between the slit sources and the screen is 1 m. If the distance between the slits is 2 mm and the wavelength of light used is 600 nm, the fringe width is**

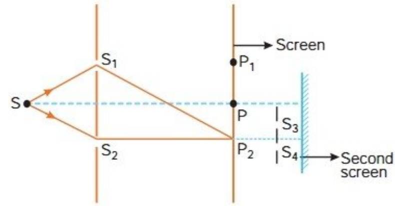
(*a*) 3 mm

(*b*) 0.3 mm

(*c*) 6 mm

(*d*) 0.6 mm

11. **Figure shows a standard two slit arrangement with slits S_1, S_2. P_1, P_2 are the two minima points on either side of P.** *[NCERT Exemplar]*



At P_2 on the screen, there is a hole and behind P_2 is a second 2- slit arrangement with slits S_3, S_4 and a second screen behind them.

(*a*) There would be no interference pattern on the second screen but it would be lighted.

(*b*) The second screen would be totally dark.

(*c*) There would be a single bright point on the second screen.

(*d*) There would be a regular two slit pattern on the second screen.

12. **The Young's double-slit experiment is performed with blue and green lights of wavelengths 4360 Å and 5460 Å respectively. If x is the distance of 4th maxima from the central one, then**

(*a*) $(x)_{blue} = (x)_{green}$ (*b*) $(x)_{blue} > (x)_{green}$

(*c*) $(x)_{blue} < (x)_{green}$ (*d*) $\frac{(x)_{blue}}{(x)_{green}} = \frac{5460}{4360}$

13. **The intensity ratio of the maxima and minima in an interference pattern produced by two coherent sources of light is 9 : 1. The intensities of the used light sources are in ratio**

(*a*) 3 : 1 (*b*) 4 : 1

(*c*) 9 : 1 (*d*) 10 : 1

14. **In a double-slit experiment instead of slits of equal widths, one slit is made twice as wide as the other. Then in the interference pattern**

(*a*) the intensity of both the maxima and the minima increase

(*b*) the intensity of maxima increase and the minima has zero intensity

(*c*) the intensity of maxima decreases and that of minima increases

(*d*) the intensity of maxima decrease and minima has zero intensity

15. **In the wave picture of light, the intensity I of light is related to the amplitude A of the wave as** *[CBSE 2023 (55/3/1)]*

(*a*) $I \propto \sqrt{A}$ (*b*) $I \propto A$ (*c*) $I \propto A^2$ (*d*) $I \propto \frac{1}{A^2}$

16. **A double slit interference experiment is carried out in air and the entire arrangement is dipped in water. The fringe width**

(*a*) increases (*b*) decreasess

(*c*) remains unchanged (*d*) fringe pattern disappears

17. **An electromagnetic radiation of frequency n wavelength λ, travelling with velocity v in air enters a glass slab of refractive index μ. The frequency, wavelength and velocity of light in the glass slab will be respectively**

(*a*) $n, 2\lambda$ and $\frac{v}{\mu}$ (*b*) $\frac{2n}{\mu}, \frac{\lambda}{\mu}$ and v

(*c*) $\frac{n}{\mu}, \frac{\lambda}{\mu}$ and $\frac{v}{\mu}$ (*d*) $n, \frac{\lambda}{\mu}$ and $\frac{v}{\mu}$

18. Yellow light is used in a single slit diffraction experiment with slit width of 0.6 mm. If yellow light is replaced by *X*-rays, then the observed pattern will reveal

(*a*) that the central maximum is narrower (*b*) more number of fringes
(*c*) less number of fringes (*d*) no diffraction pattern

19. Consider the diffraction pattern for a small pinhole. As the size of the hole is increased [*NCERT Exemplar*]

(*a*) the size decreases (*b*) the intensity increases
(*c*) the size increases (*d*) the intensity decreases

20. For light diverging from a point source [*NCERT Exemplar*]

(*a*) the wavefront is spherical.
(*b*) the intensity decreases in proportion to the distance squared.
(*c*) the wavefront is parabolic.
(*d*) the intensity at the wavefront does not depend on the distance.

21. In a single-slit diffraction experiment, the width of the slit is halved. The width of the central maximum, in the diffraction pattern, will become [*CBSE 2023 (55/3/1)*]

(*a*) half (*b*) twice (*c*) four times (*d*) one-fourth

22. In a Young's double slit experiment, the separation between the slits is 0.1 mm, the wavelength of light used is 600 nm and the interference pattern is observed on a screen 1 m away. Find the separation between bright fringes.

(*a*) 6.6 mm (*b*) 6.0 mm (*c*) 6 m (*d*) 60 cm

23. For light wave, λ is the wavelength, δ is the phase difference between two points on the wave separated by a distance of Δ. The relationship between λ, δ and Δ is

(*a*) $\Delta = \frac{2\pi}{\lambda}\delta$ (*b*) $\Delta = \frac{\lambda}{2\pi}\delta$ (*c*) $\delta = \frac{\Delta}{\lambda}$ (*d*) $\delta = \frac{\Delta\pi}{\lambda}$

24. The shape of the interference fringes in Young's double slit experiment when *D* (distance between slit and screen) is very large as compared to fringe width is nearly

(*a*) straight line (*b*) parabolic (*c*) circular (*d*) hyperbolic

Answers

1. (*c*)	**2.** (*c*)	**3.** (*d*)	**4.** (*a*)	**5.** (*a*)	**6.** (*d*)	**7.** (*b*)
8. (*c*)	**9.** (*a*)	**10.** (*b*)	**11.** (*d*)	**12.** (*c*)	**13.** (*b*)	**14.** (*a*)
15. (*c*)	**16.** (*b*)	**17.** (*d*)	**18.** (*d*)	**19.** (*a*), (*b*)	**20.** (*a*), (*b*)	**21.** (*b*)
22. (*b*)	**23.** (*b*)	**24.** (*a*)				

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(a) *Both A and R are true and R is the correct explanation of A.*
(b) *Both A and R are true but R is not the correct explanation of A.*
(c) *A is true but R is false.*
(d) *A is false and R is also false.*

1. Assertion(*A*) : It is not possible to have interference between the waves produced by two violins.

Reason (*R*) : For interference of two waves the phase difference between the waves must remain constant. [*AIIMS 2012*]

2. **Assertion** (*A*) : The phase difference between any two points on a wavefront is zero.

Reason (*R*) : Corresponding to a beam of parallel rays of light, the wavefronts are planes parallel to one another.

3. **Assertion** (*A*) : For identical coherent waves, the maximum intensity is four times the intensity due to each wave.

Reason (*R*) : Intensity is proportional to the square of amplitude.

4. **Assertion** (*A*) : Corpuscular theory fails in explaining the velocities of light in air and water.

Reason (*R*) : According to corpuscular theory, light should travel faster in denser media than in rarer media. [*AIIMS 2012*]

5. **Assertion** (*A*) : In Young's double slit experiment all frings are of equal width.

Reason (*R*) : The fringe width depends upon wavelength of light (λ) used, distane of screen from plane of slits (D) and slits separation (d). [*CBSE 2023 (55/2/1)*]

6. **Assertion** (*A*) : Light added to light can produce darkness.

Reason (*R*) : When two coherent light waves interfere, there is darkness at position of destructive interference.

7. **Assertion** (*A*) : When the apparatus of Young's double-slit experiment is brought in a liquid from air, the fringe width decrease.

Reason (*R*) : The wavelength of light decreases in the liquid.

8. **Assertion** (*A*) : The phase difference between any two points on a wavefront is zero.

Reason (*R*) : All points on a wavefront are at the same distance from the source and thus oscillate in the same phase. [*CBSE 2023 (55/1/1)*]

9. **Assertion** (*A*) : Colours are seen in thin layers of oil on the surface of water.

Reason (*R*) : White light is composed of several colours. [*AIIMS 2018*]

10. **Assertion** (*A*) : Coloured spectrum is seen when we look through a muslin cloth.

Reason (*R*) : Coloured spectrum is due to diffraction of white light passing through fine slits made by fine threads in the muslin cloth.

Answers

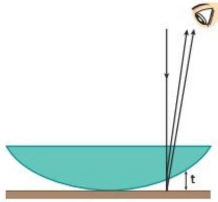
1. (*a*) **2.** (*b*) **3.** (*b*) **4.** (*a*) **5.** (*a*) **6.** (*a*) **7.** (*a*)
8. (*a*) **9.** (*b*) **10.** (*a*)

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Case-based/Passage-based Questions

Read the paragraph given below and answer the questions that follow:

1. **Newton's Rings:** The figure shows convex surface of a lens in contact with a plane glass plate. A thin film of air is formed between the two surfaces. When you view the setup with monochromatic light, you see circular interference fringes. These were studied by Newton and are called Newton's rings. When you view the setup by reflected light, the center of the pattern is black. Can you see why this should be expected?



We can use interference fringes to compare the surfaces of two optical parts by placing the two in contact and observing the interference fringes. The figure shows a photograph made during the grinding of a telescope objective lens. The lower, larger diameter, thicker disk is the correctly shaped master, and the smaller, upper disk is the lens under test. The "Contour lines" are Newton's interference fringes; each one indicates an additional distance between the specimen and the master of one half wavelength. At 10 lines from the center spot the distance between the two surfaces is 5 wavelengths, or about 0.003 mm. This isn't very good, high quality lenses are routinely ground with a precision of less than one wavelength. The surface of the primary mirror of the Hubble Space Telescope was ground to a precision of better than $\frac{1}{50}$ wavelength. Unfortunately, it was ground to incorrect specifications, creating one of the most precise errors in the history of optical technology.

(i) What principle is responsible for light spreading as it passes through a narrow slit?

(a) Interference (b) Diffraction

(c) Polarisation (d) Refraction

(ii) When viewed with white light, Newton's ring appear as

(a) alternating bright and dark rings

(b) a series of concentric rings

(c) a concentric ring pattern of rainbow colors

(d) a dark ring centred at the point of contact

(iii) Newton's rings is a natural phenomenon that involves

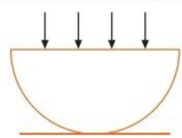
(a) an interference pattern due to reflection of light between two surfaces

(b) an interference pattern due to refraction of light between two surfaces

(c) a diffraction pattern due to reflection of light between two surfaces

(d) a diffraction pattern due to refraction of light between two surfaces

(iv) A thin slice is cut out of a glass cylinder along a line parallel to its axis. The slice is placed on a flat glass plate as shown. The observed interference fringes from this combination will be



(a) straight

(b) circular

(c) equally spaced

(d) having fringe spacing which increases as we go outwards.

OR

Two light sources are said to be coherent if they

(a) are of the same frequency, and maintain a constant phase difference

(b) are of the same amplitude, and maintain a constant phase difference

(c) are of the same frequency and amplitude

(d) are of the same frequency

2. **Diffraction:** Diffraction of light is bending of light around the corners of an object whose size is comparable with the wavelength of light. Diffration actually defines the limits of ray optics. This limit for optical instruments is set by the wavelength of light. An experimental arrangement is set up to observe the diffraction pattern due to a single slit. *[CBSE 2023 (55/3/1), Modified]*

(i) The penetration of light into the region of geometrical shadow is called

(a) polarisation (b) interference

(c) diffraction (d) refraction

(ii) To observe diffraction, the size of an obstacle

(a) should be of the same order as wavelength

(b) should be much larger than the wavelength

(c) have no relation to wavelength

(d) should be exactly $\frac{l}{2}$

(iii) Both, light and sound waves produce diffraction. It is more difficult to observe diffraction with light waves because

(a) light waves do not require medium (b) wavelength of light waves is too small

(c) light waves are transverse in nature (d) speed of light is far greater

(iv) Angular width of central maximum of a diffraction pattern of a single slit does not depend upon

(a) distance between slit and source (b) wavelength of light used

(c) width of the slit (d) frequency of light used

OR

The diffraction effect can be observed in

(a) only sound waves (b) only light waves

(c) only ultrasonic waves (d) sound as well as light waves

Explanations

1. (i) (b) The phenomenon of bending of light around the sharp corners and the spreading of light within the geometrical shadow of the opaque obstacles is called diffraction of light.

(ii) (c) When viewed with white light, it forms a concentric ring pattern of rainbow colors, because the different wavelengths of light interfere at different thickness of the air layer between the surface.

(iii) (a) Newton's rings is a phenomenon in which an interference pattern is created by the reflection of light between two surfaces; a spherical surface and an adjacent touching flat surface.

(iv) (b) The fringes are locus of equal thickness which are circular. These are called Newton's rings.

OR

(d) The two waves are perfectly coherent, if their frequency and wave form are identical and their phase difference is constant.

2. (i) (c) The bending of light around the corners is known as diffraction of light. So, the light penetrates into the region of geometrical shadow.

(ii) (a) To observe diffraction, the size of obstacle should be of the same order as that of the wavelength.

(iii) (b) It is more difficult to observe diffraction with light waves because wavelength of light waves is far too smaller compared to that of sound waves.

(iv) (a) Angular width, $\theta = \frac{\lambda}{d} = \frac{c}{\nu d}$

Hence, angular width depend upon wavelength of light used, width of slit and frequency of light used.

OR

(d) The diffraction effect can be observed in sound as well as in light waves.

CONCEPTUAL QUESTIONS

Q. 1. Why are coherent soruces required to create interference of light? [*CBSE (F) 2009*]

Ans. Coherent sources are required for sustained interference. If sources are incoherent, the intensity at a point will go on changing with time.

Q. 2. Name any two factors on which the fringe width in a Young's double-slit experiment depends. [*CBSE 2023 (55/1/1)*]

Ans. As we know, Fringe width, $\beta = \dfrac{\lambda D}{d}$.

Factors which affect β, are:

(*a*) Wavelength of light (λ)

(*b*) Width of slit (d)

Q. 3. Write the conditions on path difference under which (*i*) constructive (*ii*) destructive interference occur in Young's double slit experiment. [*CBSE 2020 (55/5/1)*]

Ans. (*i*) for constructive interference path difference, $\Delta p = n\lambda, n = 0, 1, 2, 3...$ ½

(*ii*) for destructive interference path difference, $\Delta p = (2n+1)\dfrac{\lambda}{2}, n = 0, 1, 2, 3...$ ½

[*CBSE Marking Scheme 2020 (55/5/1)*]

Q. 4. How does the fringe width of interference fringes change, when the whole apparatus of Young's experiment is kept in water (refractive index 4/3)? [*CBSE Delhi 2011*] [*HOTS*]

Ans. Fringe width, $\beta = \dfrac{D\lambda}{d} \Rightarrow \beta \propto \lambda$ for same D and d. When the whole apparatus is immersed in a transparent liquid of refractive index $n = 4/3$, the wavelength decreases to $\lambda' = \dfrac{\lambda}{n} = \dfrac{\lambda}{4/3}$. So, fringe width decreases to $\dfrac{3}{4}$ times.

Q. 5. In what way is the diffraction from each slit related to interference pattern in double slit experiment? [*CBSE Bhubaneshwar 2015*]

Ans. The intensity of interference fringes in a double slit arrangement is modulated by the diffraction pattern of each slit. Alternatively, in double slit experiment the interference pattern on the screen is actually superposition of single slit diffraction for each slit.

Q. 6. What is the shape of the wavefront on earth for sunlight? [*NCERT Exemplar*]

Ans. Spherical with huge radius as compared to the earth's radius so that it is almost a plane.

Q. 7. Why is the interference pattern not detected, when two coherent sources are far apart? [*HOTS*]

Ans. Fringe width of interference fringes, is given by $\beta = \dfrac{D\lambda}{d} \propto \dfrac{1}{d}$. If the sources are far apart; d is large; so fringe width (β) will be so small that the fringes are not resolved and they do not appear separate. That is why the interference pattern is not detected for large separation of coherent sources.

Q. 8. No interference pattern is detected when two coherent sources are infinitely close to each other. Why? [*HOTS*]

Ans. Fringe width of interference fringes is given by $\beta = \dfrac{D\lambda}{d} \propto \dfrac{1}{d}$. When d is infinitely small, fringe width β will be too large. In such a case even a single fringe may occupy the whole field of view. Hence, the interference pattern cannot be detected.

Q. 9. Consider a point at the focal point of a convergent lens. Another convergent lens of short focal length is placed on the other side. What is the nature of the wavefronts emerging from the final image? [*HOTS*] [*NCERT Exemplar*]

Ans. The focal point of a convergent lens is the position of real image formed by this lens, when object is at infinity. When another convergent lens of short focal length is placed on the other side, the combination will form a real point image at the combined focus of the two lenses. The wavefronts emerging from the final image will be spherical.

Q. 10. Why are coherent sources necessary to produce a sustained interference pattern? [*CBSE Delhi 2012*]

Ans. This is because coherent sources are needed to ensure that the positions of maxima and minima do not change with time.

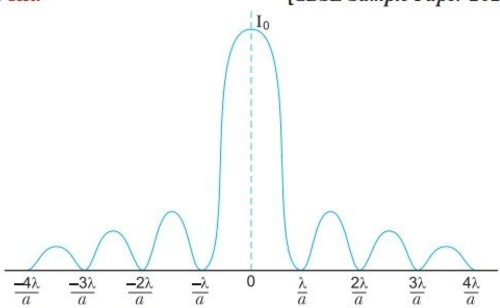
If the phase difference between wave, reaching at a point change with time intensity will change and sustained interference will not be obtained.

Very Short Answer Questions

Each of the following questions are of 2 marks.

Q. 1. Draw the graph showing intensity distribution of fringes with phase angle due to diffraction through single slit. [*CBSE Sample Paper 2021, CBSE 2023 (55/4/1)*]

Ans.



Intensity distribution of diffraction pattern.

Q. 2. State Huygens principle. How did Huygens explain the absence of the backwave? [*CBSE 2023 (55/3/1)*]

Ans. According to Huygens' principle, each point on a wave front is a source of secondary waves, which add up to give wave front at any later time which vibrating in same phase in all directions.

The absence of the back wave can be shown mathematically as we know that the amplitude of secondary wavelets is proportional to $(1 + \cos\theta)$, where θ is angle between the ray at the point of consideration and the direction of secondary wavelets. For a backward wavefront at $\theta = \pi$ so that $(1 + \cos\theta = 0)$. Thus the resultant amplitude of all the secondary wavelets at any point on the backward wavefront is zero. Hence, a backward wave point cannot exist.

Q. 3. Find the intensity at a point on a screen in Young's double slit experiment where the interfering waves of equal intensity have a path difference of (*i*) $\frac{\lambda}{4}$, and (*ii*) $\frac{\lambda}{3}$. [*CBSE (F) 2017*]

Ans. As we know, $I = 4 I_0 \cos^2\frac{\phi}{2}$

(*i*) If path difference $= \dfrac{\lambda}{4}$

$$\Rightarrow \qquad \phi = \frac{2\pi}{\lambda} \times \Delta = \frac{2\pi}{\lambda} \times \frac{\lambda}{4} = \frac{\pi}{2}$$

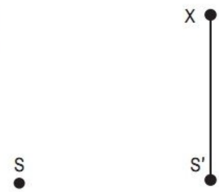
Also, $\qquad I = 4I_0 \cos^2 \dfrac{\phi}{2} = 4I_0 \cos^2 \dfrac{\pi}{4} = \mathbf{2I_0}$

(*ii*) If $\Delta = \dfrac{\lambda}{3}$

$$\Rightarrow \qquad \phi = \frac{2\pi}{\lambda} \times \frac{\lambda}{3} = \frac{2\pi}{3}$$

$$\therefore \qquad I = 4I_0 \cos^2 \frac{\phi}{2} = 4I_0 \cos^2 \left(\frac{2\pi}{3 \times 2}\right) = \mathbf{I_0}$$

Q. 4. Two waves from two coherent sources *S* and *S'* superimpose at *X* as shown in the figure. If *X* is a point on the second minima and *SX*– *S'X* is 4.5 cm. Calculate the wavelength of the waves. **[*CBSE Sample Paper, 2021*]**



Ans. For 2nd minima, $n = 2$

Path difference $= \Delta x = (2n - 1)\dfrac{\lambda}{2} = \dfrac{3\lambda}{2}$

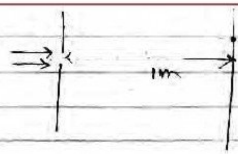
From the figure, Path Difference = SX – S'X = 4.5 cm (given)

Hence, $\qquad \Delta x = \text{SX} - \text{S'X} \quad \Rightarrow \quad \dfrac{3\lambda}{2} = 4.5$

$$\therefore \qquad \boldsymbol{\lambda = 3}\ \textbf{cm}$$

Q. 5. A parallel beam of light of wavelength 500 nm falls on a narrow slit and the resulting diffraction pattern is obtained on a screen 1 m away. If the first minimum is formed at a distance of 2.5 mm from the centre of the screen, find the (*i*) width of the slit, and (*ii*) distance of first secondary maximum from the centre of the screen. **[*CBSE 2020 (55/2/1)*]**

Ans.

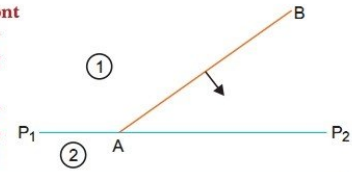


We know for first minimum
$a \sin\theta = \lambda$.
$\Rightarrow \sin\theta = \lambda/a \Rightarrow \theta = \lambda/a$ [$\because$ θ is very small]
[a = width of slit. λ = wavelength].
$\therefore$ linear distance $= D\theta = D\lambda/a$.
[D is distance between slit and screen].
Here, $D\lambda/a = 2.5$ mm
$\Rightarrow \dfrac{1 \times 500 \times 10^{-9}}{a} = 2.5 \times 10^{-3}$
$\Rightarrow a = \dfrac{500 \times 10^{-9}}{2.5 \times 10^{-3}} = 200 \times 10^{-6}$ m $\Rightarrow 2 \times 10^{-4}$ m $= 0.2$ mm.
$\therefore$ slit width $= 0.2$ mm (Ans i)
Now, angular distance ~~from se~~ for first secondary maximum
$\cancel{\theta}$ $a \sin\theta = 3\lambda/2 \Rightarrow \theta = 3\lambda/2a$.
$\therefore$ linear distance $= \dfrac{3\lambda D}{2a}$.
$\therefore$ linear distance $= 3/2 \times \dfrac{D\lambda}{a} = 3/2 \times 2.5$ mm
$= 3.75$
$\therefore$ distance $= 3.75$ mm (Ans ii)

[*Topper's Answer 2020*]

Q. 6. Define the term 'wave front of light'. A plane wave front AB propagating from denser medium (1) into a rarer medium (2) is incident on the surface P_1P_2 separating the two media as shown in fig.

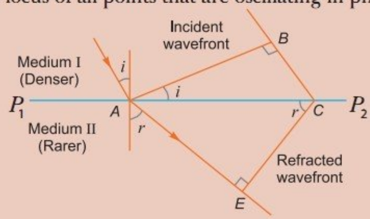
Using Huygen's principle, draw the secondary wavelets and obtain the refracted wave front in the diagram. *[CBSE 2020 (55/5/1)]*



Ans. The wave front is a surface of constant phase. **1**

Alternatively

The wave front is the locus of all points that are oscillating in phase.



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[CBSE Marking Scheme 2020 (55/5/1)]

Q. 7. Two slits are made 1 mm apart and the screen is placed 1 m away. What should be the width of each slit to obtain 10 maxima of the double slit pattern within the central maximum of the single slit pattern? *[CBSE Guwahati 2015]*

Ans. If a is the size of single slit for diffraction pattern then, for first maxima

$$\theta = \frac{\lambda}{a} \quad (n = 1)$$

and angular separation of central maxima in the diffraction pattern

$$\theta' = 2\theta = \frac{2\lambda}{a}$$

The angular size of the fringe in the interference pattern

$$\alpha = \frac{\beta}{D} = \frac{\lambda}{d}$$

If there are 10 maxima within the central maxima of the diffraction pattern, then

$$10\,\alpha = \theta'$$

$$10\left(\frac{\lambda}{d}\right) = \frac{2\lambda}{a} \quad \Rightarrow \quad a = \frac{d}{5}$$

The distance between two slits is 1 mm.

$\therefore$ Size of the single slit $a = \frac{1}{5}\text{mm} = \mathbf{0.2\ mm}$

Q. 8. Two coherent monochromatic light beams of intensities I and $4I$ superpose each other. Find the ratio of maximum and minimum intensities in the resulting beam. *[CBSE 2023 (55/1/1)]*

Ans. As we know,

$$\frac{I_{\max}}{I_{\min}} = \frac{(a_1 + a_2)^2}{(a_1 - a_2)^2} = \frac{(\sqrt{I} + 2\sqrt{I})^2}{(\sqrt{I} - 2\sqrt{I})^2} \qquad (\because a_1^2 = I, a_1 = \sqrt{I} \qquad a_2^2 = 4I, a_2 = 2\sqrt{I})$$

$$\therefore \quad \frac{I_{\max}}{I_{\min}} = \frac{[\sqrt{I}(1+2)]^2}{[\sqrt{I}(1-2)]^2} = \mathbf{\frac{9}{1}}$$

Q. 9. **(*i*) In diffraction due to a single slit, the phase difference between light waves reaching a point on the screen is 5π. Explain whether a bright or a dark fringe will be formed at the point.**

(*ii*) What should the width (a) of each slit be to obtain eight maxima of two double-slit patterns (slit separation d) within the central maximum of the single slit pattern? **[*CBSE 2023(55/4/1)*]**

Ans. (*i*) As from the relation,

$$\frac{\Delta x}{\lambda} = \frac{\theta}{2\pi}$$

$$\therefore \qquad \Delta x = \left(\frac{5\pi}{2\pi}\right)\lambda = \frac{5}{2}\lambda = \left(2 + \frac{1}{2}\right)\lambda$$

For maxima in single-slit diffraction,

Path difference, $\Delta x = \left(n + \frac{1}{2}\right)\lambda$, $n = 0, 1, 2,$

As compare from above results, we get, $n = 2$

So, the bright fringe will formed.

(*ii*) In *YDSE*,

Fringe width, $\beta_1 = 8\beta_0 = \frac{8\lambda D}{d}$ (given)

also, angular width, $\theta_1 = \frac{\beta_1}{D} = \frac{8\lambda}{d}$

For single-slit diffraction pattern,

For central maxima, $\theta_2 = \frac{2\lambda}{a}$

Now, $\theta_1 = \theta_2$

$$\frac{8\lambda}{d} = \frac{2\lambda}{a}$$

$$\therefore \qquad a = \boldsymbol{\frac{d}{4}}$$

Thus, width of each shit will be $\boldsymbol{\frac{1}{4}}$th of slit separation.

Q. 10. **In Young's double-slit experiment, the two slits are separated by a distance equal to 100 times the wavelength of light that passes through the slits. Calculate:**

(*a*) the angular separation in radians between the central maximum and the adjacent maximum.

(*b*) the distance between these two maxima on a screen 50 cm from the slits. **[*CBSE 2023 (55/1/1)*]**

Ans. Here, $d = 100\,\lambda$ (given), $D = 50$ cm.

(*a*) Angular width, $\theta = \frac{\lambda}{d} = \frac{\lambda}{100\lambda} = \mathbf{0.01\ rad}$.

(*b*) Fringe width, $\beta = \frac{\lambda D}{d} = \frac{\lambda}{100\lambda} \times 50 = \frac{50}{100} = \mathbf{0.5\ cm}$.

Short Answer Questions

Each of the following questions are of 3 marks.

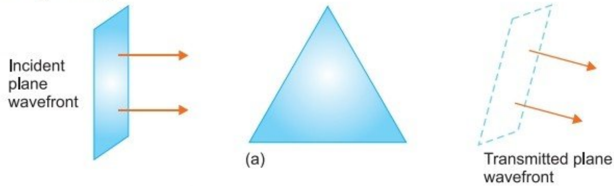
Q. 1. **Draw the diagrams to show the behaviour of plane wavefronts as they (*a*) pass through a thin prism, and (*b*) pass through a thin convex lens and (*c*) reflect by a concave mirror.**

[*CBSE Bhubaneshwar 2015, CBSE Sample Paper 2021*]

OR

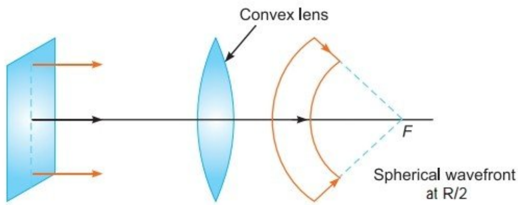
Use Huygens principle to show reflection/refraction of a plane wave by (*i*) concave mirror, and (*ii*) a convex lens. **[*CBSE 2023 (55/3/1)*]**

Ans. The behaviour of a thin prism, a thin convex lens and a concave mirror are shown in fig. (*a*), (*b*) and (*c*) respectively.



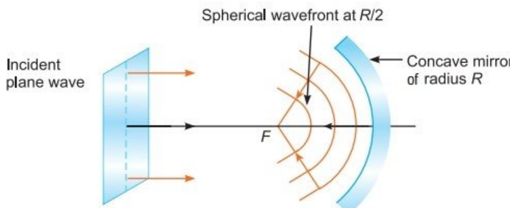
(a)

A plane wavefront after refraction through prism is plane.



(b)

A plane wavefront emerging after refraction through convex lens is spherical and converges to focus *F*.



(c)

A plane wavefront emerging after reflection through concave mirror is spherical and converges to focus *F*.

Q. 2. What is the shape of the wavefront in each of the following cases: **[*CBSE Delhi 2009*]**

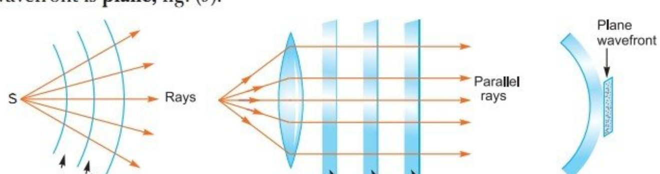
(*a*) light diverging from a point source.

(*b*) light emerging out of a convex lens when a point source is placed at its focus.

(*c*) the portion of a wavefront of light from a distant star intercepted by the earth.

Ans. (*a*) The wavefront will be **spherical** of increasing radius, fig. (*a*).

(*b*) The rays coming out of the convex lens, when point source is at focus, are parallel, so wavefront is **plane,** fig. (*b*).



(a) Spherical wavefront (b) Plane wavefront (c) Plane wavefront (*c*) The wavefront starting from star is spherical. As star is very far from the earth, so the wavefront intercepted by earth is a very small portion of a sphere of large radius; which is **plane** (*i.e.*, wavefront intercepted by earth is plane), fig. (*c*).

Q. 3. Explain the following, giving reasons:

(*i*) When monochromatic light is incident on a surface separating two media, the reflected and refracted light both have the same frequency as the incident frequency.

(*ii*) When light travels from a rarer to a denser medium, the speed decreases. Does this decrease in speed imply a reduction in the energy carried by the wave?

(*iii*) In the wave picture of light, intensity of light is determined by the square of the amplitude of the wave. What determines the intensity in the photon picture of light? [*CBSE Central 2016*]

Ans. (*i*) Reflection and refraction arise through interaction of incident light with atomic constituents of matter which vibrate with the same frequency as that of the incident light. Hence frequency remains unchanged.

(*ii*) No; when light travels from a rarer to a denser media, its frequency remains unchanged. According to quantum theory of light, the energy of light photon depends on frequency and not on speed.

(*iii*) For a given frequency, intensity of light in the photon picture is determined by the number of photon incident normally on a crossing an unit area per unit time.

Q. 4. (*a*) Write the necessary conditions to obtain sustained interference fringes.
Also write the expression for the fringe width.

(*b*) In Young's double slit experiment, plot a graph showing the variation of fringe width versus the distance of the screen from the plane of the slits keeping other parameters same. What information can one obtain from the slope of the curve?

(*c*) What is the effect on the fringe width if the distance between the slits is reduced keeping other parameters same? [*CBSE Patna 2015*]

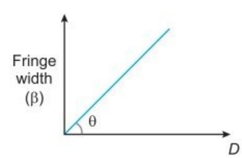
Ans. (*a*) **Conditions for sustained interference:**

(*i*) The interfering sources must be coherent *i.e.*, sources must have same frequency and constant initial phase.

(*ii*) Interfering waves must have same or nearly same amplitude, so that there may be contrast between maxima and minima.

Fringe width, $\beta = \dfrac{D\lambda}{d}$

where D = distance between slits and screen.
d = separation between slits.
λ = wavelength of light used.



(*b*) **Information from the slope:**

Wavelength, $\lambda = \text{Slope} \times d = d.\tan\theta$

(*c*) **Effect:** From relation, $\beta = \dfrac{\lambda D}{d}$

Fringe width, $\beta \propto \dfrac{1}{d}$

If distance d between the slits is reduced, the size of fringe width will increase.

Q. 5. For a single slit of width "*a*", the first minimum of the interference pattern of a monochromatic light of wavelength λ occurs at an angle of $\dfrac{\lambda}{a}$. At the same angle of $\dfrac{\lambda}{a}$, we get a maximum for two narrow slits separated by a distance "*a*". Explain. [*CBSE Delhi 2014*]

Ans. Case I: The overlapping of the contributions of the wavelets from two halves of a single slit produces a minimum because corresponding wavelets from two halves have a path difference of $\lambda/2$.

Case II: The overlapping of the wavefronts from the two slits produces first maximum because these wavefronts have the path difference of λ.

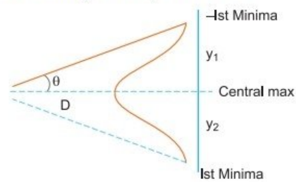
Q. 6. In the experiment on diffraction due to a single slit, show that

(i) the intensity of diffraction fringes decreases as the order (n) increases.

(ii) angular width of the central maximum is twice that of the first order secondary maximum. *[CBSE (F) 2011]*

Ans. (i) The reason is that the intensity of central maximum is due to constructive interference of wavelets from all parts of slit, the first secondary maximum is due to contribution of wavelets from one third part of slit (wavelets from remaining two parts interfere destructively) the second secondary maximum is due to contribution of wavelets from one fifth part only and so on.

(ii) For first minima $a \sin\theta = \lambda$ or $a\theta = \lambda$ $\quad \tan\theta = \frac{y_1}{D}$



$\Rightarrow \quad \theta = \frac{y_1}{D}$ (for θ is small, $\sin\theta \approx \theta$ and $\tan\theta \approx \theta$)

$\Rightarrow \quad \frac{ay_1}{D} = \lambda \qquad y_1 = \frac{\lambda D}{a} = y_2$

Hence the angular width of central maximum $= 2\theta = \frac{2\lambda}{a}$

Width of secondary maximum = Separation between nth and $(n+1)$th minima

For minima $\theta_n = \frac{n\lambda}{a} \quad \theta_{n+1} = (n+1)\frac{\lambda}{a}$

Angular width of secondary maximum $= (n+1)\frac{\lambda}{a} - \frac{n\lambda}{a} = \frac{\lambda}{a}$

Hence β = Angular width $\times D = \frac{\lambda D}{a}$

Thus central maximum has twice the angular width of secondary maximum.

Q. 7. What is the effect on the interference fringes in Young's double slit experiment due to each of the following operations? Justify your answers.

(a) The screen is moved away from the plane of the slits.

(b) The separation between slits is increased.

(c) The source slit is moved closer to the plane of double slit. *[CBSE 2020 (55/5/1)]*

Ans. (a) Fringe width increases, $\beta = \frac{\lambda D}{d} \Rightarrow \beta \propto D$

(b) Fringe width decreases $\left(\beta \propto \frac{1}{d}\right)$

(c) Since condition $\frac{s}{S} < \frac{\lambda}{d}$ is not satisfied, no interference will be obtained and frenges disappear.

Q. 8. Two coherent light waves of intensity 5×10^{-2} Wm^{-2} each super-impose and produce the interference pattern on a screen. At a point where the path difference between the waves is $\lambda/6$, λ being wavelength of the wave, find the

(a) phase difference between the waves

(b) resultant intensity at the point

(c) resultant intensity in terms of the intensity at the maximum *[CBSE 2020 (55/4/1)]*

Ans. (a) Phase difference $= \frac{2\pi}{\lambda}$(path difference Δ)

$$\Delta = \frac{\lambda}{6} \text{ (Given)} \qquad \text{then, } \phi = \frac{2\pi}{\lambda} \times \frac{\lambda}{6} = \frac{\pi}{3}$$

(b) $I = 2I_0(1 + \cos\phi) = 2I_0\left(1 + \cos\frac{\pi}{3}\right) = 2I_0\left(1 + \frac{1}{2}\right) = 3I_0$

$$= 3 \times 5 \times 10^{-2}\ \text{Wm}^{-2}$$

$$= \mathbf{15 \times 10^{-2}\ Wm^{-2}}$$

(*c*) Maximum intensity $= 4I_0$

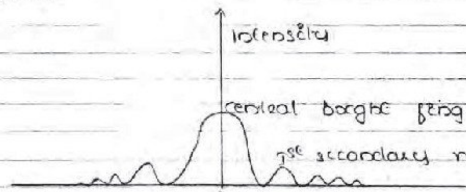
$$I_m = 4I_0,\ I = 3I_0$$

$$\frac{I}{I_m} = \frac{3}{4} \quad \Rightarrow \quad I = \frac{3}{4} I_m$$

Q. 9. Draw the intensity pattern for single slit diffraction and double slit interference for (*i*) the fringes produced in interference, and (*ii*) the Hence, state two difference between interference and diffraction. **[*CBSE AI 2017*]**

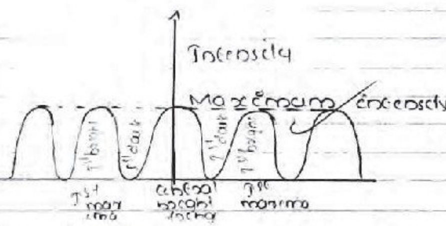
Ans. Intensity pattern of single slit diffraction

The central bright fringe has the maximum intensity and the intensity decreases as we move on to the either sides of the central maximum.



Intensity pattern for double slit interference:

All the bright fringes possess the same intensity



Interference	Diffraction
All the bright fringes are of equal intensity	The principal maxima posses the highest intensity and the intensity decreases as we move on to either sides from the principal maxima
All bright fringes are of equal width	The width of fringes also increases from principal maxima to either sides.
Maxima occurs at $\theta_n = \frac{n\lambda}{d}$	Minima occurs at $\theta_n = \frac{n\lambda}{d}$
Good contrast between bright and dark fringes	Poor contrast between bright and dark fringes

[*Topper's Answer 2017*]

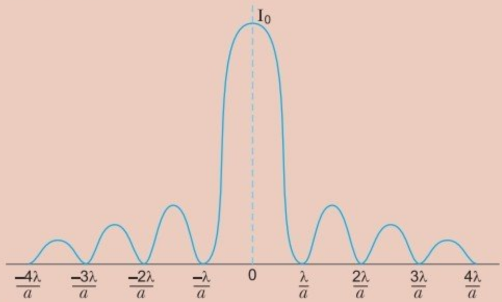
Q. 10. A plane wavefront of light of wavelength 'λ' is incident normally on a narrow slit of width 'a' and a diffraction pattern is observed on a screen at a distance 'D' from the slit.

(*i*) Depict the intensity distribution in the pattern observed.

(*ii*) Obtain the expression for the first maximum from the central maximum.

[CBSE 2022 (55/2/1), Term-2]

Ans. (*i*) Intensity distribution curve 1½



(*ii*) For maximum,

$$a \sin \theta = (n + \frac{1}{2})\lambda$$ ½

For first Maximum; $n = 1$ ½

For small θ; $a\theta = \frac{3\lambda}{2} \Rightarrow \theta = \frac{3\lambda}{2a}$

$$\Rightarrow \frac{x}{D} = \frac{3}{2}\frac{\lambda}{a}$$

$$\therefore \quad x = \frac{3}{2}\frac{\lambda D}{a}$$ ½

[CBSE Marking Scheme 2022 (55/2/1), Term-2]

Q. 11. A beam of light consisting of two wavelengths 600 nm and 500 nm is used in a Young's double slit experiment. The slit separation is 1.0 mm and the screen is kept 0.60 m away from the plane of the slits. Calculate :

(*i*) the distance of the second bright fringe from the central maximum for wavelength 500 nm, and

(*ii*) the least distance from the central maximum where the bright fringes due to both the wavelengths coincide. ***[CBSE 2022 (55/3/3), Term-2]***

Ans.

Fringe width of any wavelength in Young's ~~dob~~ double slit experiment is given by (β)

$$\boxed{\beta = \frac{D\lambda}{d}}$$

$D \rightarrow$ distance between slits and screen

$\lambda \rightarrow$ wavelength of light

$d \rightarrow$ distance between the slits

Hence,

• Fringe width of 600 nm ⇒ $\beta_{600} = \frac{D\lambda}{d} = \frac{0.60 \times 600 \times 10^{-9}}{1.0 \times 10^{-3}}$

$= 3.6 \times 10^{-4}$ m

$\boxed{\beta_{600} = 0.36 \text{ mm}}$

Fringe width of 500 nm ⇒ $\beta_{500} = \frac{D\lambda}{d} = \frac{0.6 \times 500 \times 10^{-9}}{1.0 \times 10^{-3}}$

$\boxed{\beta_{500} = 0.30 \text{ mm}}$

(i) Position of second bright fringe of 500 nm ⇒ $y_2 = 2\beta_{500}$

Position of central maximum ⇒ $y_1 = 0$

⇒ Distance between second bright fringe and central maximum for $\lambda = 500$ nm $= y_2 - y_1 = 2\beta_{500}$

$= \boxed{0.6 \text{ mm}}$
$= \boxed{6 \times 10^{-4} \text{ m}}$

Ans: Thus, the distance is 0.60 mm (or 6×10^{-4} m)

(ii) Position of m^{th} bright fringe from central maxima for $\lambda = 500$ nm $= m\beta_{500}$

Position of n^{th} bright fringe from central maxima for $\lambda' = 600$ nm $= n\beta_{600}$

If this position is same for both

$m\beta_{500} = n\beta_{600}$ ⇒ $m \times 0.30 = n \times 0.36$

$\boxed{5m = 6n}$ [where m, n are integers]

$\frac{m}{n} = \frac{6}{5}$

⇒ For smallest distance m = 6, n = 5

⇒ distance $= m\beta_{500} = n\beta_{600} = 6 \times 0.3$ mm

$= 5 \times 0.36$ mm

$= \boxed{1.8 \text{ mm}}$

Ans: Thus the least distance is 1.8 mm (or 1.8×10^{-3} m)

[Topper's Answer 2022]

Q. 12. In the diffraction due to a single slit experiment, the aperture of the slit is 3 mm. If monochromatic light of wavelength 620 nm is incident normally on the slit, calculate the separation between the first order minima and the 3rd order maxima on one side of the screen. The distance between the slit and the screen is 1.5 m. *[CBSE 2019 (55/1/1)]*

Ans. Condition for minima

$$a \sin\theta = n\lambda \qquad ...(i)$$

and condition for secondary maxima

$$a \sin\theta = \left(n + \frac{1}{2}\right)\lambda$$

The first order minima $[n = 1]$

$$a \sin\theta = \lambda, \qquad \tan\theta = \frac{y_1}{D}$$

$$\sin\theta = \frac{\lambda}{a} \quad \Rightarrow \quad \theta = \frac{\lambda}{a}, \; \theta = \frac{y_1}{D} \qquad [\because \text{for } \theta \text{ is small}, \sin\theta \simeq \theta \text{ and } \tan\theta \simeq \theta]$$

$$\therefore \qquad \frac{y_1}{D} = \frac{\lambda}{a} \quad \Rightarrow \quad y_1 = \frac{\lambda D}{a}$$

Also 3rd order maxima

$$a \sin\theta = \left(3 + \frac{1}{2}\right)\lambda \quad \Rightarrow \quad a \sin\theta = \frac{7}{2}\lambda$$

$$\frac{y_3}{D} = \frac{7}{2}\frac{\lambda}{a} \qquad \Rightarrow \quad y_3 = \frac{7}{2}\frac{\lambda D}{a}$$

Distance between first order minima from centre of the central maxima

$$y_1 = \frac{\lambda D}{a}$$

Distance of third order maxima from centre of the central maxima

$$y_3 = \frac{7\lambda D}{2a}$$

Distance between first order minima and third order maxima,

$$y_3 - y_1 = \frac{7}{2}\frac{\lambda D}{a} - \frac{\lambda D}{a} = \frac{\lambda D}{a}\left[\frac{7}{2} - 1\right] = \frac{\lambda D}{a} \times \frac{5}{2}$$

$$= \frac{620 \times 10^{-9} \times 1.5}{3 \times 10^{-3}} \times \frac{5}{2} = \mathbf{7.75 \times 10^{-4}\ m}$$

Q. 13. A parallel beam of light of wavelength 600 nm is incident normally on a slit of width 0.2 mm. If the resulting diffraction pattern is observed on a screen 1 m away, find the distance of

(*i*) first minimum, and

(*ii*) second maximum, from the central maximum *[CBSE 2022 (55/1/1),Term-2]*

Ans. (*i*) $y = \dfrac{\lambda D}{a}, \qquad [n = 1]$ ½

$$= \frac{600 \times 10^{-9} \times 1}{0.2 \times 10^{-3}}$$ ½

$$= 3 \times 10^{-3} \text{ m} = 3 \text{ mm}$$ ½

(*ii*) $y = \left(n + \dfrac{1}{2}\right)\dfrac{\lambda D}{a}, \qquad [n = 2]$ ½

$$\Rightarrow \quad y = \left(2 + \frac{1}{2}\right)\frac{\lambda D}{a}$$ ½

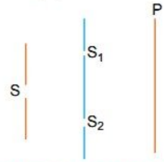
$$\therefore \quad y = \frac{5}{2} \times \frac{600 \times 10^{-9} \times 1}{0.2 \times 10^{-3}}$$

$$= 7.5 \times 10^{-3} = 7.5 \text{ mm}$$ ½

[CBSE Marking Scheme 2022 (55/1/1), Term-2]

Q. 14. **(*i*) In a Young's double-slit experiment $SS_2 - SS_1 = \frac{\lambda}{4}$, where S_1 and S_2 are the two slits as shown in the figure.**

Find the path difference $(S_2P - S_1P)$ for constructive and destructive interference at P.



(*ii*) What is the effect on the interference fringes in a Young's double-slit experiment, if the monochromatic source S is replaced by a source of white light? ***[CBSE 2023 (55/4/1)]***

Ans. (*i*) Net path difference between two waves reaching on the screen through two slits is given as

$$SS_2P - SS_1P = (SS_2 - SS_1) + (S_2P - S_1P)$$

$$\Delta x = \frac{\lambda}{4} + (S_2P - S_1P)$$

For constructive interference $\Delta x = n\lambda$

$$\therefore \quad (S_2P - S_1P) = n\lambda - \frac{\lambda}{4} = \lambda\left(n - \frac{1}{4}\right) \text{ where, } n = 0, 1, 2, ...$$

For destructive interference,

$$\Delta x = (2n-1)\frac{\lambda}{2}$$

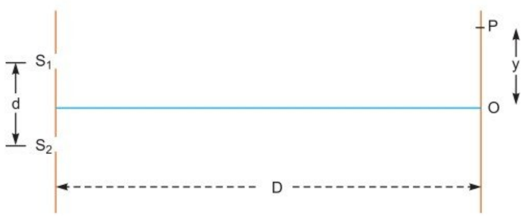
also, $$\Delta x = \frac{\lambda}{4} + (S_2P - S_1P)$$

$$\therefore \quad (S_2P - S_1P) = (2n-1)\frac{\lambda}{2} - \frac{\lambda}{4}$$

$$= \frac{\lambda}{4}[4n-3], \text{ where } n = 1, 2, 3....$$

(*ii*) If monochromatic light source is replaced by a source of white light, the interference patterns due to different components of colours of white light will overlap. The central bright fringes for all colours are at same point, hence the central fringes is white, but all other fringes are coloured.

Q. 15. **The intensity at the central maxima (O) in a Young's double slit experiment is I_0. If the distance OP equals one-third of the fringe width of the pattern, show that the intensity at point P would be $\frac{I_0}{4}$.** ***[CBSE (F) 2011, 2012]***



Ans. Fringe width $(\beta) = \frac{\lambda D}{d}$

$$y = \frac{\beta}{3} = \frac{\lambda D}{3d}$$

Path diff $(\Delta P) = \frac{yd}{D} \Rightarrow \Delta P = \frac{\lambda D}{3d} \cdot \frac{d}{D} = \frac{\lambda}{3}$

$\therefore \quad \Delta\phi = \frac{2\pi}{\lambda} \cdot \Delta P = \frac{2\pi}{\lambda} \cdot \frac{\lambda}{3} = \frac{2\pi}{3}$

Intensity at central maxima, $I_0 = 4I$, where I = Intensity due to one slit.

Intensity at point P, $I_P = 4I\cos^2\left(\frac{\Delta\phi}{2}\right) = I_0 \cos^2 \frac{\Delta\phi}{2}$

$$= I_0\left[\cos\frac{2\pi}{3\times 2}\right]^2 = I_0\left(\frac{1}{2}\right)^2 = \frac{\mathbf{I_0}}{\mathbf{4}}$$

Q. 16. In a diffraction pattern due to a single slit, how will the angular width of central maximum change, if

(*i*) Orange light is used in place of green light,

(*ii*) the screen is moved closer to the slit,

(*iii*) the slit width is decreased ? Justify your answer in each case. ***[CBSE 2022 (55/3/3), Term-2]***

Ans.

Angular width of the central maximum in single slit $(\theta) = \frac{2\lambda}{a}$

$\lambda \rightarrow$ wavelength of light
$a \rightarrow$ width of slit

Orange light has greater wavelength than green light. As the angular width of the central maxima is directly proportional to wavelength of light, ~~the~~ its value will increase is orange light is used in place of green light.

$\theta \propto \lambda$

$\lambda_{orange} > \lambda_{green}$

$\Rightarrow \boxed{\theta_{orange} > \theta_{green}}$

Ans: Increase in angular width.

The distance between the slit and screen is decreased when the screen is moved ~~cros~~ closer to slit. As the angular width is independent of the distance between the slit and screen its value will not change

$\theta \propto D^0$

$\boxed{\theta_i = \theta_f}$

Ans: No change in angular width

As the angular width is inversely proportional to slit width, it value will increase on decreasing width.

$$\theta \propto \frac{1}{a}$$

$$a_i > a_f$$

$$\therefore \boxed{\theta_f > \theta_i}$$

Ans: Increase in angular width.

[*Topper's Answer* 2022]

Q. 17. A beam of light consisting of two wavelength 650 nm and 520 nm, is used to obtain interference fringes in a Young's double slit experiment on a screen 1.2 m away. The separation between the slits is 2 mm.

(*a*) Find the distance of the third bright fringe on the screen from the central maximum for wavelength 650 nm.

(*b*) What is the least distance from the central maximum when the bright fringes due to both the wavelength coincide? **[*NCERT*]**

Ans. Given, $\lambda_1 = 650 \text{ nm} = 650 \times 10^{-9} \text{ m}$,

$$\lambda_2 = 520 \text{ nm} = 520 \times 10^{-9} \text{ m}$$

(*a*) For bright fringes,

$$y_n = \frac{nD\lambda_1}{d} \qquad [n = 3]$$

$$\Rightarrow \qquad y_3 = \frac{3 \times 1.2 \times 650 \times 10^{-9}}{2 \times 10^{-3}} = 1.17 \times 10^{-3} \text{m} = \mathbf{1.17 \text{ mm}}$$

(*b*) For least distance of coincidence of fringes, there must be a difference of 1 in order of λ_1 and λ_2.

$$\Rightarrow \qquad n_1\beta_1 = n_2\beta_2 \text{ (given)} \quad \Rightarrow \quad \frac{n_1 D\lambda_1}{d} = \frac{n_2 D\lambda_2}{d} \quad \Rightarrow \quad n_1\lambda_1 = n_2\lambda_2$$

As $\lambda_1 > \lambda_2$, $n_1 < n_2$

If bright fringe will coincide at a least distance y, $n_1 = n, n_2 = n + 1$

$$\therefore \qquad (y_n)\lambda_1 = (y_{n+1})\lambda_2$$

$$\Rightarrow \qquad \frac{nD\lambda_1}{d} = \frac{(n+1)D\lambda_2}{d}$$

$$\Rightarrow \qquad n\lambda_1 = (n + 1)\lambda_2$$

$$\Rightarrow \qquad n = \frac{\lambda_2}{\lambda_1 - \lambda_2} = \frac{520 \text{ nm}}{(650 - 520) \text{ nm}} = \frac{520}{130} = 4$$

$$\therefore \text{ Least distance, } \quad y_{\min} = \frac{nD\lambda_1}{d} = \frac{4 \times 1.2 \times 650 \times 10^{-9}}{2 \times 10^{-3}}$$

$$= 1.56 \times 10^{-3} \text{ m}$$

$$= \mathbf{1.56 \text{ mm}}$$

Long Answer Questions

Each of the following questions are of 5 marks.

Q. 1. Using Huygens' principle, draw a diagram to show propagation of a wavefront originating from a monochromatic point source. Explain briefly.

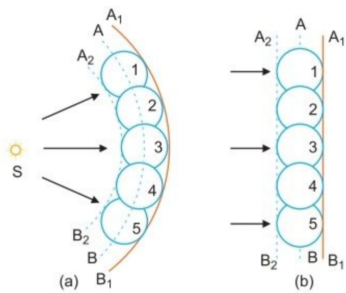
Ans. Propagation of Wavefront from a Point Source:

This principle is useful for determining the position of a given wavefront at any time in the future if we know its present position. The principle may be stated in three parts as follows:

(*i*) Every point on a given wavefront may be regarded as a source of new disturbance.

(*ii*) The new disturbances from each point spread out in all directions with the velocity of light and are called the ***secondary wavelets.***

(*iii*) The surface of tangency to the secondary wavelets in forward direction at any instant gives the new position of the wavefront at that time.



Let us illustrate this principle by the following example:

Let AB shown in the fig. be the section of a wavefront in a homogeneous isotropic medium at $t = 0$. We have to find the position of the wavefront at time t using Huygens' principle. Let v be the velocity of light in the given medium.

(*a*) Take the number of points 1, 2, 3, ... on the wavefront AB. These points are the sources of secondary wavelets.

(*b*) At time t the radius of these secondary wavelets is vt. Taking each point as centre, draw circles of radius vt.

(*c*) Draw a tangent A_1B_1 common to all these circles in the forward direction.

This gives the position of new wavefront at the required time t.

The Huygens' construction gives a backward wavefront also shown by dotted line A_2B_2 which is contrary to observation. The difficulty is removed by assuming that the intensity of the spherical wavelets is not uniform in all directions; but varies continuously from a maximum in the forward direction to a minimum of zero in the backward direction.

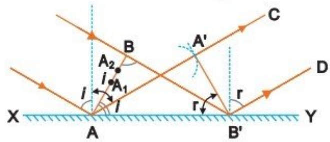
The directions which are normal to the wavefront are called rays, *i.e.*, a ray is the direction in which the disturbance is propagated.

Q. 2. Define the term wavefront. Using Huygen's wave theory, verify the law of reflection.

[*CBSE (55/1/1) 2019, 2020 (55/2/1), 2023 (55/5/1)*]

Ans. **Wavefront:** A wavefront is a locus of particles of medium all vibrating in the same phase.

Law of Reflection: Let XY be a reflecting surface at which a wavefront is being incident obliquely. Let v be the speed of the wavefront and at time $t = 0$, the wavefront touches the surface XY at A. After time t, the point B of wavefront reaches the point B' of the surface.



According to Huygen's principle each point of wavefront acts as a source of secondary waves. When the point A of wavefront strikes the reflecting surface, then due to presence of reflecting surface, it cannot advance further; but the secondary wavelet originating from point A begins to spread in all directions in the first medium with speed v. As the wavefront AB advances further, its points A_1, A_2, A_3 ... etc. strike the reflecting surface successively and send spherical secondary wavelets in the first medium.

First of all the secondary wavelet starts from point A and traverses distance AA' $(= vt)$ in first medium in time t. In the same time t, the point B of wavefront, after travelling a distance BB', reaches point B' (of the surface), from where the secondary wavelet now starts. Now taking A as centre we draw a spherical arc of radius AA' $(= vt)$ and draw tangent $A'B'$ on this arc from point B'. As the incident wavefront AB advances, the secondary wavelets starting from points between A and B', one after the other and will touch $A'B'$ simultaneously. According to Huygen's principle wavefront $A'B'$ represents the new position of AB, *i.e.*, $A'B'$ is the reflected wavefront corresponding to incident wavefront AB.

Now in right-angled triangles ABB' and $AA'B'$

$$\angle ABB' = \angle AA'B' \quad \text{(both are equal to } 90°\text{)}$$

$$\text{side } BB' = \text{side } AA' \quad \text{(both are equal to } vt\text{)}$$

and side AB' is common.

i.e., both triangles are congruent.

$\therefore \qquad \angle BAB' = \angle AB'A'$

i.e., incident wavefront AB and reflected wavefront $A'B'$ make equal angles with the reflecting surface XY. As the rays are always normal to the wavefront, therefore the incident and the reflected rays make equal angles with the normal drawn on the surface XY, *i.e.*,

Angle of incidence (i) = Angle of reflection (r)

This is the second law of reflection.

Since AB, $A'B'$ and XY are all in the plane of paper, therefore the perpendiculars dropped on them will also be in the same plane. Therefore we conclude that ***the incident ray, reflected ray and the normal at the point of incidence, all lie in the same plane.*** This is the first law of reflection. Thus Huygen's principle explains both the laws of reflection.

Q. 3. (*a*) How is a wavefront defined? Using Huygen's constructions draw a figure showing the propagation of a plane wave refracting at a plane surface separating two media. Hence verify Snell's law of refraction. **[*CBSE 2023 (55/1/1)*]**

When a light wave travels from rarer to denser medium, the speed decreases. Does it imply reduction its energy? Explain. **[*CBSE Delhi 2008, 2013, (F) 2011, 2012*]**

(*b*) When monochromatic light travels from a rarer to a denser medium, explain the following, giving reasons:

(*i*) **Is the frequency of reflected and refracted light same as the frequency of incident light?**

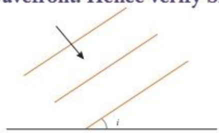
(*ii*) **Does the decrease in speed imply a reduction in the energy carried by light wave?**

[*CBSE Delhi 2013*]

OR

A plane wavefront propagating in a medium of refractive index 'n_1' is incident on a plane surface making the angle of incidence 'i' as shown in the figure. It enters into a medium of refractive index 'n_2' ($n_2 > n_1$). Use Huygens' construction of secondary wavelets to trace the propagation of the refracted wavefront. Hence verify Snell's law of refraction.

[*CBSE (F) 2015, 2023 (55/5/1)*]



Ans. (*a*) **Wavefront:** A wavefront is a locus of all particles of medium vibrating in the same phase.

Huygen's Principle: Refer point 1 of Points to remember.

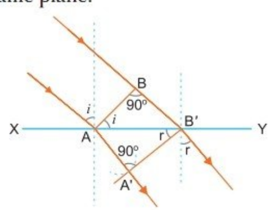
Proof of Snell's law of Refraction using Huygen's wave theory: When a wave starting from one homogeneous medium enters the another homogeneous medium, it is deviated from its path. This phenomenon is called **refraction**. In transversing from first medium to another medium, the frequency of wave remains unchanged but its speed and the wavelength both are changed. Let XY be a surface separating the two media '1' and '2'. Let v_1 and v_2 be the speeds of waves in these media.

Suppose a plane wavefront AB in first medium is incident obliquely on the boundary surface XY and its end A touches the surface at A at time $t = 0$ while the other end B reaches the surface at point B' after time-interval t. Clearly $BB' = v_1t$. As the wavefront AB advances, it strikes the points between A and B' of boundary surface. According to Huygen's principle, secondary spherical wavelets originate from these points, which travel with speed v_1 in the first medium and speed v_2 in the second medium.

First of all secondary wavelet starts from A, which traverses a distance AA' ($= v_2t$) in second medium in time t. In the same time-interval t, the point of wavefront traverses a distance BB' ($= v_1t$) in first medium and reaches B', from, where the secondary wavelet now starts. Clearly $BB' = v_1t$ and $AA' = v_2t$.

Assuming A as centre, we draw a spherical arc of radius AA' ($= v_2t$) and draw tangent $B'A'$ on this arc from B'. As the incident wavefront AB advances, the secondary wavelets start from points between A and B', one after the other and will touch $A'B'$ simultaneously. According to Huygen's principle $A'B'$ is the new position of wavefront AB in the second medium. ***Hence A'B' will be the refracted wavefront.***

First law: As AB, $A'B'$ and surface XY are in the plane of paper, therefore the perpendicular drawn on them will be in the same plane. As the lines drawn normal to wavefront denote the rays, therefore we may say that the incident ray, refracted ray and the normal at the point of incidence all lie in the same plane.



This is the first law of refraction.

Second law: Let the incident wavefront AB and refracted wavefront $A'B'$ make angles i and r respectively with refracting surface XY.

In right-angled triangle $AB'B$, $\angle ABB' = 90°$

$$\therefore \qquad \sin i = \sin \angle BAB' = \frac{BB'}{AB'} = \frac{v_1 t}{AB'} \qquad ...(i)$$

Similarly in right-angled triangle $AA'B'$, $\angle AA'B' = 90°$

$$\therefore \qquad \sin r = \sin \angle AB'A' = \frac{AA'}{AB'} = \frac{v_2 t}{AB'} \qquad ...(ii)$$

Dividing equation (*i*) by (*ii*), we get

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \text{constant} \qquad ...(iii)$$

As the rays are always normal to the wavefront, therefore the incident and refracted rays make angles i and r with the normal drawn on the surface XY *i.e.* i and r are the angle of incidence and angle of refraction respectively. According to equation (*iii*):

The ratio of sine of angle of incidence and the sine of angle of refraction for a given pair of media is a constant and is equal to the ratio of velocities of waves in the two media. This is the second law of refraction, and is called the Snell's law.

(*b*) (*i*) If the radiation of certain frequency interact with the atoms/molecules of the matter, they start to vibrate with the same frequency under forced oscillations.

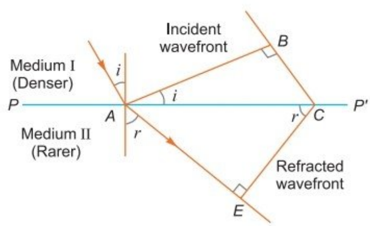
Thus, the frequency of the scattered light (Under reflection and refraction) equals to the frequency of incident radiation.

(*ii*) No, energy carried by the wave depends on the frequency of the wave, but not on the speed of the wave.

Q. 4. Use Huygens' principle to show how a plane wavefront propagates from a denser to rarer medium. Hence, verify Snell's law of refraction.

[CBSE Allahabad 2015, Sample Paper 2016, 2021; 2019(55/1/1), 2020(55/1/1), 2023(55/1/1)]

Ans. We assume a plane wavefront AB propagating in denser medium incident on the interface PP' at angle i as shown in Fig. Let t be the time taken by the wave front to travel a distance BC. If v_1 is the speed of the light in medium I.



So, $\qquad BC = v_1 t$

In order to find the shape of the refracted wavefront, we draw a sphere of radius $AE = v_2 t$, where v_2 is the speed of light in medium II (rarer medium). The tangent plane CE represents the refracted wavefront.

In ΔABC, $\qquad \sin i = \dfrac{BC}{AC} = \dfrac{v_1 t}{AC}$

and in ΔACE, $\quad \sin r = \dfrac{AE}{AC} = \dfrac{v_2 t}{AC}$

$$\therefore \qquad \frac{\sin i}{\sin r} = \frac{BC}{AE} = \frac{v_1 t}{v_2 t} = \frac{v_1}{v_2} \qquad \ldots(i)$$

Let c be the speed of light in vacuum

So, $$n_1 = \frac{c}{v_1} \text{ and } n_2 = \frac{c}{v_2}$$

$$\frac{n_2}{n_1} = \frac{v_1}{v_2} \qquad \ldots(ii)$$

From equations (*i*) and (*ii*), we have

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1}$$

$$n_1 \sin i = n_2 \sin r$$

It is known as Snell's law.

Q. 5. **(*a*) In Young's double slit experiment, discuss the conditions for (*i*) constructive, and (*ii*) destructive interference at a point on the screen. Draw a graph showing variation of the resultant intensity in the interference pattern against position '*X*' on the screen.**

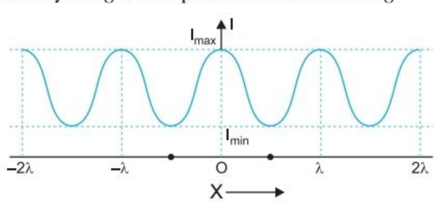
[*CBSE Delhi 2016, (AI) 2012*]

(*b*) Compare and contrast the pattern which is seen with two coherently illuminated narrow slits in Young's experiment with that seen for a coherently illuminated single slit producing diffraction.

Ans. (*a*) **Conditions of Constructive and Destructive Interference:**

When two waves of same frequency and constant initial phase difference travel in the same direction along a straight line simultaneously, they superpose in such a way that the intensity of the resultant wave is maximum at certain points and minimum at certain other points. The phenomenon of redistribution of intensity due to superposition of two waves of same frequency and constant initial phase difference is called the interference. The waves of same frequency and constant initial phase difference are called **coherent waves**. At points of medium where the waves arrive in the same phase, the resultant intensity is maximum and the interference at these points is said to be **constructive**. On the other hand, at points of medium where the waves arrive in opposite phase, the resultant intensity is minimum and the interference at these points is said to be **destructive**. The positions of maximum intensity are called **maxima** while those of minimum intensity are called **minima**. The interference takes place in sound and light both.

Variation of Intensity of light with position x is shown in fig.



(*b*) **Comparison of two Slit Young's Interference pattern and Single slit diffraction pattern**

Both patterns are the result of wave nature of light; both patterns contain maxima and minima. Interference pattern is the result of superposing two coherent wave while the diffraction pattern is the superposition of large number of waves originating from each point on a single slit.

Differences: (*i*) In Young's two slit experiment; all maxima are of same intensity while in diffraction at a single slit, the intensity of central maximum is maximum and it falls rapidly for first, second order secondary maxima on either side of it.

(*ii*) In Young's interference the fringes are of equal width while in diffraction at a single slit, the central maximum is twice as wide as other maxima. The intensity falls as we go to successive maxima away from the centre on either side.

(*iii*) In a single slit diffraction pattern of width a, the first minimum occurs at λ/a; while in two slit interference pattern of slit separation a, we get maximum at the same angle $\frac{\lambda}{a}$.

Q. 6. Two harmonic waves of monochromatic light

$$y_1 = a \cos \omega t \text{ and } y_2 = a \cos(\omega t + \phi)$$

are superimposed on each other. Show that maximum intensity in interference pattern is four times the intensity due to each slit. Hence write the conditions for constructive and destructive interference in terms of the phase angle ϕ. [*CBSE South 2016*]

Ans. The resultant displacement will be given by

$$\begin{aligned} y &= y_1 + y_2 \\ &= a \cos \omega t + a \cos(\omega t + \phi) \\ &= a[\cos \omega t + \cos(\omega t + \phi)] \\ &= 2a \cos(\phi/2) \cos(\omega t + \phi/2) \end{aligned}$$

The amplitude of the resultant displacement is $2a \cos(\phi/2)$

The intensity of light is directly proportional to the square of amplitude of the wave. The resultant intensity will be given by

$$I = 4a^2 \cos^2 \frac{\phi}{2}$$

$\therefore$ Intensity $= 4I_0 \cos^2\left(\frac{\phi}{2}\right)$, where $I_0 = a^2$ is the intensity of each harmonic wave

At the maxima, $\phi = \pm 2n\pi$

$$\therefore \quad \cos^2 \frac{\phi}{2} = 1$$

At the maxima, $I = 4I_0 = 4 \times$ intensity due to one slit

$$I = 4I_0 \cos^2\left(\frac{\phi}{2}\right)$$

For constructive interference, I is maximum.

It is possible when $\cos^2\left(\frac{\phi}{2}\right) = 1; \frac{\phi}{2} = n\pi; \phi = 2n\pi$

For destructive interference, I is minimum, *i.e.*, $I = 0$

It is possible when $\cos^2\left(\frac{\phi}{2}\right) = 0; \frac{\phi}{2} = \frac{(2n-1)\pi}{2}; \phi = (2n \pm 1)\frac{\pi}{2}$

Q. 7. What is interference of light? Write two essential conditions for sustained interference pattern to be produced on the screen.

Draw a graph showing the variation of intensity versus the position on the screen in Young's experiment when (*a*) both the slits are opened and (*b*) one of the slits is closed.

What is the effect on the interference pattern in Young's double slit experiment when:

(*i*) screen is moved closer to the plane of slits?

(*ii*) separation between two slits is increased?

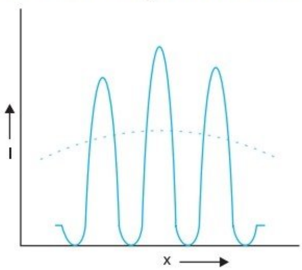
Explain your answer in each case.

Ans. **Interference of light:** When two waves of same frequency and constant initial phase difference travel in the same direction along a straight line simultaneously, they superpose in such a way that the intensity of the resultant wave is maximum at certain points and minimum at certain other points. This phenomenon of redistribution of energy due to superposition of two waves of same frequency and constant initial phase difference is called interference.

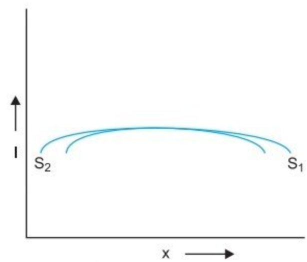
Conditions for Sustained Interference of Light Waves

To obtain sustained (well-defined and observable) interference pattern, the intensity must be maximum and zero at points corresponding to constructive and destructive interference. For the purpose following conditions must be fulfilled:

- *The two interfering sources must be coherent and of same frequency, i.e., the sources should emit light of the same wavelength or frequency and their initial phase should remain constant*. If this condition is not satisfied the phase difference between the interfering waves will vary continuously. As a result the resultant intensity at any point will vary with time being alternately maximum and minimum, just like the phenomenon of beats in sound.
- *The interfering waves must have equal amplitudes*. Otherwise the minimum intensity will not be zero and there will be general illumination.



(*a*) When both the slits are opened. The dashed curve is the single slit intensity for comparison



(*b*) When one of the slits is closed.

The variation of intensity I versus the position x on the screen in Young's experiment.

Fringe width, $\beta = \dfrac{D\lambda}{d}$.

(*i*) $\beta \propto D$, therefore with the decrease of separation between the plane of slits and screen, the fringe width decreases.

(*ii*) On increasing the separation between two slits (d), the fringe separation decreases as β is inversely proportional to $d\left(i.e., \beta \propto \dfrac{1}{d}\right)$.

Q. 8. What is diffraction of light? Draw a graph showing the variation of intensity with angle in a single slit diffraction experiment. Write one feature which distinguishes the observed pattern from the double slit interference pattern. **[*CBSE (F) 2013*]**

How would the diffraction pattern of a single slit be affected when:

(*i*) the width of the slit is decreased?

(*ii*) the monochromatic source of light is replaced by a source of white light?

Ans. **Diffraction of Light:** When light is incident on a narrow opening or an obstacle in its path, it is bent at the sharp edges of the obstacle or opening. This phenomenon is called diffraction of light.

For graph refer point 5 of Points to remember.

In an interference pattern all the maxima have the same intensity while in diffraction pattern the maxima are of different intensities. For example in Young's double slit experiment all maxima are of the same intensity and in diffraction at a single slit, the central maximum have the maximum intensity and it falls rapidly for first, second orders secondary maxima on either side of it.

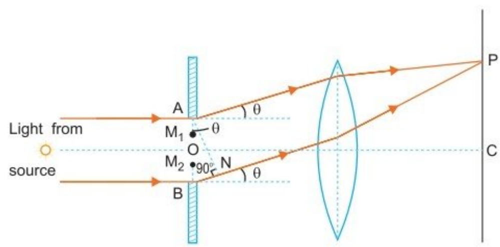
(*i*) **When the width of the slit is decreased:** From the relation $\sin\theta = \frac{\lambda}{a}$, we find that if the width of the slit (a) is decreased, then for a given wavelength, $\sin\theta$ is large and hence θ is large. Hence diffraction maxima and minima are quite distant on either side of θ.

(*ii*) With monochromatic light, the diffraction pattern consists of alternate bright and dark bands. If white light is used central maximum is white and on either side, the diffraction bands are coloured.

Q. 9. Describe diffraction of light due to a single slit. Explain formation of a pattern of fringes obtained on the screen and plot showing variation of intensity with angle θ in single slit diffraction. *[CBSE Delhi 2010, (F) 2013, (AI) 2014]*

Ans. **Diffraction of light at a single slit:** When monochromatic light is made incident on a single slit, we get diffraction pattern on a screen placed behind the slit. The diffraction pattern contains bright and dark bands, the intensity of central band is maximum and goes on decreasing on both sides.

Explanation: Let AB be a slit of width 'a' and a parallel beam of monochromatic light is incident on it. According to Fresnel the diffraction pattern is the result of superposition of a large number of waves, starting from different points of illuminated slit.



Let θ be the angle of diffraction for waves reaching at point P of screen and AN the perpendicular dropped from A on wave diffracted from B.

The path difference between rays diffracted at points A and B,

$$\Delta = BP - AP = BN$$

In ΔANB, $\angle ANB = 90°$ and $\angle BAN = \theta$

$$\therefore \quad \sin\theta = \frac{BN}{AB} \text{ or } BN = AB\sin\theta$$

As AB = width of slit $= a$

$\therefore$ Path difference, $\quad \Delta = a\sin\theta \quad$ ...(*i*)

To find the effect of all coherent waves at P, we have to sum up their contribution, each with a different phase. This was done by Fresnel by rigorous calculations, but the main features may be explained by simple arguments given below:

At the central point C of the screen, the angle θ is zero. Hence the waves starting from all points of slit arrive in the same phase. This gives maximum intensity at the central point C.

Minima: Now we divide the slit into two equal halves AO and OB, each of width $\frac{a}{2}$. Now for every point, M_1 in AO, there is a corresponding point M_2 in OB, such that $M_1 M_2 = \frac{a}{2}$; then path difference between waves arriving at P and starting from M_1 and M_2 will be $\frac{a}{2}\sin\theta = \frac{\lambda}{2}$. This means that the contributions from the two halves of slit AO and OB are opposite in phase and so cancel each other. Thus above equation gives the angle of diffraction at which intensity falls to zero. Similarly it may be shown that the intensity is zero for $\sin\theta = \frac{n\lambda}{a}$, with n as integer. Thus the general condition of **minima** is

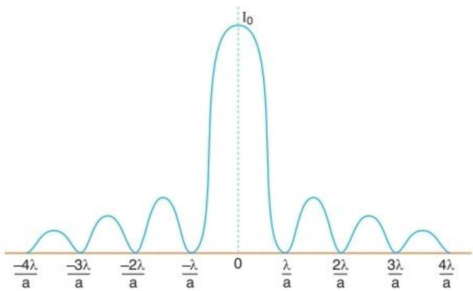
$$a \sin\theta = n\lambda \qquad ...(ii)$$

Secondary Maxima: Let us now consider angle θ such that

$$\sin\theta = \theta = \frac{3\lambda}{2a}$$

which is midway between two dark bands given by

$$\sin\theta = \theta = \frac{\lambda}{a} \text{ and } \sin\theta = \theta = \frac{2\lambda}{a}$$



Let us now divide the slit into three parts. If we take the first two parts of slit, the path difference between rays diffracted from the extreme ends of the first two parts

$$\frac{2}{3}a\sin\theta = \frac{2}{3}a \times \frac{3\lambda}{2a} = \lambda$$

Then the first two parts will have a path difference of $\frac{\lambda}{2}$ and cancel the effect of each other. The remaining third part will contribute to the intensity at a point between two minima. Clearly there will be a maxima between first two minima, but this maxima will be of much weaker intensity than central maximum. This is called *first secondary maxima*. In a similar manner we can show that there are secondary maxima between any two consecutive minima; and the intensity of maxima will go on decreasing with increase of order of maxima. In general the position of nth maxima will be given by

$$a\sin\theta = \left(n + \frac{1}{2}\right)\lambda, \qquad [n = 1,2,3,4,....]$$

The intensity of secondary maxima decreases with increase of order n because with increasing n, the contribution of slit decreases.

For $n = 2$, it is one-fifth, for $n = 3$, it is one-seventh and so on.

Questions for Practice

1. Choose and write the correct option in the following questions.

(*i*) In a Young's double-slit experiment, the fringe width is found to be β. If the entire apparatus is immersed in a liquid of refractive index μ, the new fringe width will be

[CBSE 2023 (55/4/1)]

(*a*) β (*b*) μβ (*c*) $\frac{\beta}{\mu}$ (*d*) $\frac{\beta}{\mu^2}$

(*ii*) Angular width of interference fringe depends on

(*a*) distance between slit and screen (*b*) wavelength of light

(*c*) ratio of the wavelength and slit width (*d*) width of slit

(*iii*) A linear aperture whose width is 0.02 cm is placed immediately in front of a lens of focal length 60 cm. The aperture is illuminated normally by a parallel beam of wavelength 5×10^{-5} cm. The distance of the first dark band of the differaction pattern from the centre of the screen is

(*a*) 0.10 cm (*b*) 0.25 cm (*c*) 0.20 cm (*d*) 0.15 cm

(*iv*) The shape of the interference fringes in Young's double slit experiment when D (distance between slit and screen) is very large as compared to fringe width is nearly

(*a*) straight line (*b*) parabolic (*c*) circular (*d*) hyperbolic

(*v*) A plane wavefront is incident on a concave mirror of radius of curvature R. The radius of the refracted wave front will be *[CBSE 2023 (55/4/1)]*

(*a*) $2R$ (*b*) R (*c*) $\frac{R}{2}$ (*d*) $\frac{R}{4}$

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

(*a*) ***Both A and R are true and R is the correct explanation of A.***

(*b*) ***Both A and R are true but R is not the correct explanation of A.***

(*c*) ***A is true but R is false.***

(*d*) ***A is false and R is also false.***

(*i*) **Assertion (*A*) :** No interference pattern is detected when two coherent sources are infinitely close to each other.

Reason (*R*) : Fringe width is inversely proportional to separation between the slit.

(*ii*) **Assertion (*A*) :** To observe diffraction of light, the size of obstacle/aperture should be of the order of 10^{-7} m.

Reason (*R*) : 10^{-7} m is the order of wavelength of visible light. *[AIIMS 2012]*

3. Define a wavefront. *[CBSE Sample Paper 2021]*

4. State the reason, why two independent sources of light cannot be considered as coherent sources.

5. How does the fringe width, in Young's double-slit experiment, change when the distance of separation between the slits and screen is doubled?

6. When monochromatic light travels from one medium to another, its wavelength changes but frequency remains the same. Explain. *[CBSE Delhi 2011]*

7. Light of wavelength 5000 Å propagating in air gets partly reflected from the surface of water. How will the wavelengths and frequencies of the reflected and refracted light be affected?

[CBSE Delhi 2015]

8. What will be the effect on interference fringes if red light is replaced by blue light?

[CBSE Delhi 2013]

9. How does the angular separation between fringes in single-slit diffraction experiment change when the distance of separation between the slit and screen is doubled? *[CBSE (AI) 2012]*

10. In a single-slit diffraction experiment, the width of the slit is made double the original width. How does this affect the size and intensity of the central diffraction band? *[CBSE (AI) 2012]*

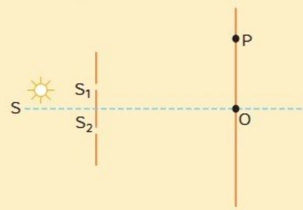
11. Find the intensity at a point on a screen in Young's double slit experiment where the interfering waves of equal intensity have a path difference of (*i*) $\frac{\lambda}{4}$, and (*ii*) $\frac{\lambda}{3}$.

12. What should be the width of each slit to obtain n maxima of double slit pattern within the central maxima of single slit pattern? *[CBSE Sample Paper 2021]*

13. Monochromatic light of wavelength 588 nm is incident from air to water interface. Find the wavelength and speed of the refracted light. The refractive index of water is $\frac{4}{3}$.

[CBSE 2020 (55/3/1)]

14. The figure shows a modified Young's double slit experimental set-up. Here $SS_2 - SS_1 = \lambda/4$.



(*a*) Write the condition for constructive interference.

(*b*) Obtain an expression for the fringe width.

15. (*a*) The refractive index of glass is 1.5. What is the speed of light in glass? (Speed of light in vacuum is 3.0×10^8 ms^{-1}).

(*b*) Is the speed of light in glass independent of the colour of light? If not, which of the two colours, red and violet, travels slower in the glass prism? *[NCERT]*

16. In Young's double slit experiment the slits are separated by 0.28 mm and the screen is placed 1.4 m away. The distance between the central bright fringe and the fourth fringe is measured to be 1.2 cm. Determine the wavelength of light used in this experiment. *[NCERT]*

17. In Young's double slit experiment using monochromatic light of wavelength λ the intensity at a point on the screen where path difference is λ is K units. What is the intensity of light at a point where path difference is $\frac{\lambda}{3}$? *[NCERT] [CBSE Delhi 2012]*

18. (*a*) If one of two identical slits producing interference in Young's experiment is covered with glass, so that the light intensity passing through it is reduced to 50%, find the ratio of the maximum and minimum intensity of the fringe in the interference pattern.

(*b*) What kind of fringes do you expect to observe if white light is used instead of monochromatic light?

19. In a Young's double slit experiment using light of wavelength 600 nm, the slit separation is 0.8 mm and the screen is kept 1.6 m from the plane of the slits. Calculate

(*i*) the fringe width

(*ii*) the distance of (*a*) third minimum and (*b*) fifth maximum, from the central maximum.

[*CBSE 2022 (55/3/1), Term-2*]

20. In a single slit diffraction experiment, light of wavelength λ illuminates the slit of width '*a*' and the diffraction pattern is observed on a screen.

(*a*) Show the intensity distribution in the pattern with the angular position θ.

(*b*) How are the intensity and angular width of central maxima affected when

(*i*) width of slit is increased, and

(*ii*) separation between slit and screen is decreased? **[*CBSE 2020 (55/1/2)*]**

21. Answer the following questions:

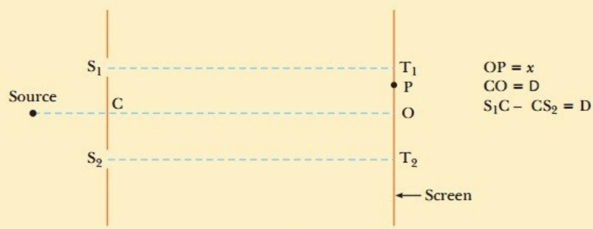
(*a*) In a single slit diffraction experiment, the width of the slit is made double the original width. How does this affect the size and intensity of the central diffraction band?

(*b*) How is the width of the central maximum changed when red light is replaced by blue?

(*c*) In what way is diffraction from each slit related to the interference pattern in a double slit experiment? **[*CBSE 2019 (55/5/3)*]**

22. Monochromatic light of wavelength 589 nm is incident from air on a water surface. What is the wavelength, frequency and speed of (*a*) reflected and (*b*) refracted light? Refractive index of water is 1.33. **[*NCERT*]**

23. Consider a two slit interference arrangements such that the distance of the screen from the slits is half the distance between the slits.



Obtain the value of D in terms of λ such that the first minima on the screen fall at a distance D from the centre O. **[*CBSE Sample Paper 2017*]**

24. Use Huygen's principle to explain the formation of diffraction pattern due to a single slit illuminated by a monochromatic source of light.

When the width of slit is made double the original width, how this affect the size and intensity of the central diffraction band? **[*CBSE Delhi 2012*]**

25. A beam of light consisting of two wavelengths, 800 nm and 600 nm is used to obtain the interference fringes in a Young's double slit experiment on a screen placed 1.4 m away. If the two slits are separated by 0.28 mm, calculate the least distance from the central bright maximum where the bright fringes of the two wavelengths coincide. **[*CBSE (AI) 2012*]**

26. Two wavelengths of sodium light 590 nm and 596 nm are used, in turn, to study the diffraction taking place at a single slit of aperture 2×10^{-4} m. The distance between the slit and the screen is 1.5 m. Calculate the separation between the positions of the first maxima of the diffraction pattern obtained in the two cases. **[*CBSE Delhi 2013*]**

27. (*a*) In Young's double slit experiment, two slits are 1 mm apart and the screen is placed 1 m away from the slits. Calculate the fringe width when light of wavelength 500 nm is used.

(*b*) What should be the width of each slit in order to obtain 10 maxima of the double slits pattern within the central maximum of the single slit pattern? [*CBSE East 2016*]

Answers

1. (*i*) (*c*) (*ii*) (*c*) (*iii*) (*d*) (*iv*) (*a*) (*v*) (*c*)

2. (*i*) (*b*) (*ii*) (*a*)

11. (*i*) $2I_0$ (*ii*) I_0

13. 441 nm, 2.25×10^{-8} m/s

15. 2×10^8 ms^{-1}

16. 600 nm

17. $\frac{1}{4}K$

18. (*a*) 34 : 1

19. (*i*) 1.2 mm (*ii*) (*a*) 3 mm (*b*) 6 mm

22. (*a*) 589 nm, 3×10^8 ms^{-1}, 5.1×10^{14} Hz (*b*) 44 nm, 2.26×10^8 ms^{-1}, 5.1×10^{14} Hz

23. $\dfrac{\lambda}{2(\sqrt{5}-1)}$ 25. 12×10^{-3} m

26. 0.065 mm 27. (*a*) 5×10^{-4} m (*b*) 2×10^{-4} m

11 Dual Nature of Matter and Radiation

POINTS TO REMEMBER

1. Dual Nature of Radiations

It is well known that the phenomena of interference, diffraction and polarisation indicate that light has wave nature. But some phenomena like photoelectric effect, Compton effect, emission and absorption of radiation could not be explained by wave nature.

These were explained by particle (quantum) nature of light. Thus, light (radiation) has dual nature.

2. Quantum Nature of Light: Concept of a Photon

Some phenomena like photoelectric effect, Compton effect, Raman effect could not be explained by wave theory of light. Therefore, quantum theory of light was proposed by Einstein. According to quantum theory of light "light is propagated in bundles of small energy, each bundle being called a photon and possessing energy."

$$E = h\nu = \frac{hc}{\lambda}$$

where ν is frequency, λ is wavelength of light and h is Planck's constant $= 6.63 \times 10^{-34}$ joule second and c = speed of light in vacuum $= 3 \times 10^8$ m/s.

Momentum of photon, $p = \dfrac{h\nu}{c} = \dfrac{h}{\lambda}$

Rest mass of photon = 0

Dynamic or kinetic mass of photon, $m = \dfrac{h\nu}{c^2} = \dfrac{h}{c\lambda}$

3. Photoelectric Effect

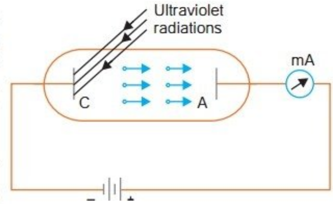
The phenomenon of emission of electrons from a metallic surface by the use of light (or radiant) energy is called *photoelectric effect*. The phenomenon was discovered by Lenard. For photoelectric emission, the metal used must have low work function, *e.g.*, alkali metals. *Caesium* is the best metal for photoelectric effect.

4. Hertz's Observations

The phenomenon of photoelectric effect was discovered by Heinrich Hertz in 1887. While performing an experiment for production of electromagnetic waves by means of spark discharge, Hertz observed that sparks occurred more rapidly in the air gap of his transmitter when ultraviolet radiations was directed at one of the metal plates. Hertz could not explain his observations.

5. Lenard's Observations

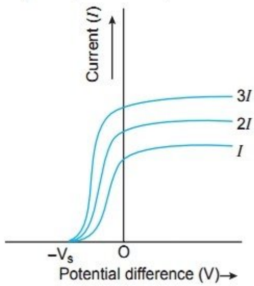
Phillip Lenard observed that when ultraviolet radiations were made incident on the emitter plate of an evacuated glass tube enclosing two metal plates (called electrodes), current flows in the circuit, but as soon as ultraviolet radiation falling on the emitter plate was stopped, the current flow stopped. These observations indicate that when ultraviolet radiations fall on the emitter (cathode) plate C, the electrons are ejected from it, which are attracted towards anode plate A. The electrons flow through the evacuated glass tube, complete the circuit and current begins to flow in the circuit.



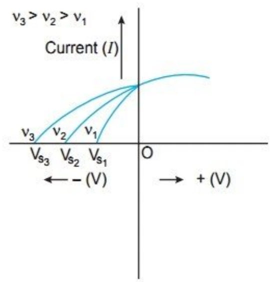
6. Characteristics of Photoelectric Effect

(*i*) **Effect of Intensity:** Intensity of light means the energy incident per unit area per second. For a given frequency, if intensity of incident light is increased, the photoelectric current increases and with decrease of intensity, the photoelectric current decreases; but the stopping potential remains the same.

Intensity of radiations can be increased/decreased by varying the distance between source and metal plate (or emitter).



(*a*)



(*b*)

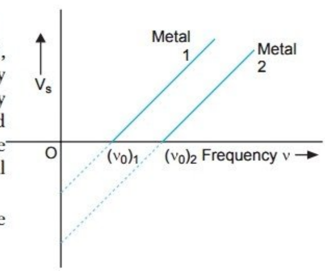
This means that the *intensity of incident light affects the photoelectric current but the maximum kinetic energy of photoelectrons remains unchanged as shown in fig (b).*

(*ii*) **Effect of Frequency:** When the intensity of incident light is kept fixed and frequency is increased, the photoelectric current remains the same; but the stopping potential increases.

If the frequency is decreased, the stopping potential decreases and at a particular frequency of incident light, the stopping potential becomes zero. This value of frequency of incident light for which the stopping potential is zero is called *threshold frequency* ν_0. If the frequency of incident light (ν) is less than the threshold frequency (ν_0) no photoelectric emission takes place.

Thus, *the increase of frequency increases the maximum kinetic energy of photoelectrons but the photoelectric current remain unchanged.*

(*iii*) **Effect of Photometal:** When frequency and intensity of incident light are kept fixed and photometal is changed, we observe that stopping potential (V_s) versus frequency (ν) graphs are parallel straight lines, cutting frequency axis at different points (Fig.). This shows that threshold frequencies are different for different metals, the slope (V_S / ν) for all the metals is same and hence a universal constant.



(*iv*) **Effect of Time:** There is no time lag between the incidence of light and the emission of photoelectrons.

7. Some Definitions

Work Function: The minimum energy required to free an electron from its metallic bonding is called work function. It is denoted by W or ϕ and is usually expressed in electron volt ($1\ \text{eV} = 1.6 \times 10^{-19}$ J).

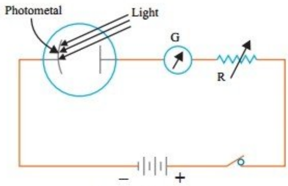
Threshold Frequency: The minimum frequency of incident light which is just capable of ejecting electrons from a metal is called the threshold frequency. It is denoted by ν_0. It is different for different metal.

Stopping Potential: The minimum retarding potential applied to anode of a photoelectric tube which is just capable of stopping photoelectric current is called the stopping potential. It is denoted by V_0 (or V_S)

8. Einstein's Explanation of Photoelectric Effect: Einstein's Photoelectric Equation

Einstein extended Planck's quantum idea for light to explain photoelectric effect.

The assumptions of Einstein's theory are:



Photoelectric cell

1. The photoelectric effect is the result of collision of a photon of incident light and an electron of photometal.
2. The electron of photometal is bound with the nucleus by coulomb attractive forces. The minimum energy required to free an electron from its bondage is called work function (W).
3. The incident photon interacts with a single electron and loses its energy in two parts:
   (*i*) in releasing the electron from its bondage, and
   (*ii*) in imparting kinetic energy to emitted electron.

   Accordingly, if $h\nu$ is the energy of incident photon, then from law of conservation of energy

   $$h\nu = W + E_k$$

   or maximum kinetic energy of photoelectrons, $E_k = \frac{1}{2}mv_{\max}^2 = h\nu - W$

   where W is work function. This equation is referred as *Einstein's photoelectric equation* and explains all experimental results of photoelectric effect. If V_s is stopping potential, then

   $$E_k = \frac{1}{2}mv_{\max}^2 = eV_S$$

   Stopping potential, $V_s = \frac{h}{e}\nu - \frac{W}{e}$

   The slope of E_k versus ν graph is h.

   The slope of V_S versus ν graph is $\frac{h}{e}$.

9. Photocell

A photocell is a device which converts light energy into electrical energy. It is also called electric eye.

10. Matter Waves: Wave Nature of Particles

Light exhibits particle aspects in certain phenomena (*e.g.*, photoelectric effect, emission and absorption of radiation), while wave aspects in other phenomena (*e.g.*, interference, diffraction and polarisation). That is, light has dual nature. In analogy with dual nature of light, de Broglie thought in terms of dual nature of matter.

11. de Broglie Hypothesis

Louis de Broglie postulated that the **material particles** (*e.g.*, electrons, protons, α-particles, atoms, etc.) may exhibit wave aspect. Accordingly, *a moving material particle behaves as wave and the wavelength associated with material particle is*

$$\lambda = \frac{h}{p} = \frac{h}{mv}, \quad \text{where } p \text{ is momentum.}$$

If E_k is kinetic energy of moving material particle, then $p = \sqrt{2mE_k}$

$$\lambda = \frac{h}{\sqrt{2mE_k}}$$

i.e.,

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mE_k}}$$

The wave associated with material particle is called the ***de Broglie wave or matter wave***. The de Broglie hypothesis has been confirmed by diffraction experiments.

For charged particles associated through a potential of V volt,

$$E_k = qV$$

$$\lambda = \frac{h}{\sqrt{2mqV}}$$

For electrons, $q = e = 1.6 \times 10^{-19}$ C, $m = 9 \times 10^{-31}$ kg

$$\lambda = \frac{12.27}{\sqrt{V}} \times 10^{-10} \text{m} = \frac{12.27}{\sqrt{V}} \text{Å} \quad \text{(Only for electrons)}$$

For electron orbiting in an atom, de Broglie wavelength is given as $\lambda = \frac{h}{p} = \frac{h}{mv}$

For neutral particles in thermal equilibrium at absolute temperature T, $E_k = kT$

$$\lambda = \frac{h}{\sqrt{2mkT}}$$

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Multiple Choice Questions

Choose and write the correct option(s) in the following questions.

1. **A particle is dropped from a height H. The de Broglie wavelength of the particle as a function of height is proportional to** *[NCERT Exemplar]*

   (*a*) H (*b*) $H^{1/2}$
   (*c*) H^0 (*d*) $H^{-1/2}$

2. **The wavelength of a photon needed to remove a proton from a nucleus which is bound to the nucleus with 1 MeV energy is nearly** *[NCERT Exemplar]*

   (*a*) 1.2 nm (*b*) 1.2×10^{-3} nm
   (*c*) 1.2×10^{-6} nm (*d*) 1.2×10^{1} nm

3. **Consider a beam of electrons (each electron with energy E_0) incident on a metal surface kept in an evacuated chamber. Then** *[NCERT Exemplar]*

   (*a*) no electrons will be emitted as only photons can emit electrons.
   (*b*) electrons can be emitted but all with an energy, E_0.
   (*c*) electrons can be emitted with any energy, with a maximum of $E_0 - \phi$ (ϕ is the work function).
   (*d*) electrons can be emitted with any energy, with a maximum of E_0.

4. **The threshold wavelength for photoelectric emission from a material is 5200 Å. Photoelectrons will be emitted when this material is illuminated with monochromatic radiation from a:**

   (*a*) 50 watt infrared lamp
   (*b*) 1000 watt infrared lamp
   (*c*) 1 watt ultraviolet lamp
   (*d*) 1 watt infrared lamp

5. **A photoelectric cell is illuminated by a point source of light 1 m away. The plate emits electrons having stopping potential V. Then**

   (*a*) V decreases as distance increase
   (*b*) V increases as distance increase
   (*c*) V is independent of distance (r)
   (*d*) V becomes zero when distance increases or decreases

6. **In a photoelectric experiment, the stopping- potential for the incident light of wavelength 4000 Å is 2 volt. If the wavelength be changed to 3000 Å, the stopping-potential will be**
(*a*) 2 volt (*b*) less than 2 volt
(*c*) zero (*d*) more than 2 volt.

7. **The work-function for a metal is 3 eV. To emit a photoelectron of energy 2 eV from the surface of this metal, the wavelength of the incident light should be**
(*a*) 6187 Å (*b*) 4125 Å (*c*) 12375 Å (*d*) 2486 Å

8. **A photocell connected in an electrical circuit is placed at a distance '*d*' from a source of light. As a result, current *I* flows in the circuit. What will be the current in the circuit when the distance is reduced to '*d*/2'?** **[*CBSE 2020 (55/4/1)*]**
(*a*) I (*b*) $2I$ (*c*) $4I$ (*d*) $I/2$

9. **A graph is plotted between the stopping potential (on *y*-axis) and the frequency of incident radiation (on *x*-axis) for a metal. The product of the slope of the straight line obtained and the magnitude of charge on an electron is equal to** **[*CBSE 2023 (55/3/1)*]**
(*a*) h (*b*) $\frac{h}{c}$ (*c*) $\frac{2h}{c}$ (*d*) $\frac{h}{2c}$

10. **A proton, a neutron, an electron and an α-particle have same energy. Then their de Broglie wavelengths compare as** **[*NCERT Exemplar*]**
(*a*) $\lambda_p = \lambda_n > \lambda_e > \lambda_\alpha$ (*b*) $\lambda_\alpha < \lambda_p = \lambda_n > \lambda_e$
(*c*) $\lambda_e < \lambda_p = \lambda_n > \lambda_\alpha$ (*d*) $\lambda_e = \lambda_p = \lambda_n = \lambda_\alpha$

11. **Light of frequency 6.4×10^{14} Hz is incident on a metal of work function 2.14 eV. The maximum kinetic energy of the emitted electrons is about** **[*CBSE 2023 (55/3/1)*]**
(*a*) 0.25 eV (*b*) 0.51 eV (*c*) 1.02 eV (*d*) 0.10 eV

12. **Relativistic corrections become necessary when the expression for the kinetic energy $\frac{1}{2}mv^2$, becomes comparable with mc^2, where *m* is the mass of the particle. At what de Broglie wavelength will relativistic corrections become important for an electron?** **[*NCERT Exemplar*]**
(*a*) $\lambda = 10$ nm (*b*) $\lambda = 10^{-1}$ nm
(*c*) $\lambda = 10^{-4}$ nm (*d*) $\lambda = 10^{-6}$ nm

13. **Monochromatic light of wavelength 667 nm is produced by a helium neon laser. The power emitted is 9 mW. The number of photons arriving per second on the average at a target irradiated by this beam is**
(*a*) 3×10^{16} (*b*) 9×10^{15} (*c*) 3×10^{19} (*d*) 9×10^{17}

14. **Electrons used in an electron microscope are accelerated by a voltage of 25 kV. If the voltage is increased to 100 kV then the de Broglie wavelength associated with the electrons would**
(*a*) increase by 2 times (*b*) decrease by 2 times
(*c*) decrease by 4 times (*d*) increase by 4 times

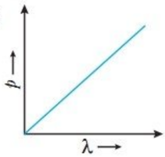
15. **An electron (mass *m*) with an initial velocity $\vec{v} = v_0\hat{i}$ is in an electric field $\vec{E} = E_0\hat{j}$. If $\lambda_0 = h/mv_0$, it's de Breoglie wavelength at time *t* is given by** **[*NCERT Exemplar*]**
(*a*) λ_0 (*b*) $\lambda_0\sqrt{1 + \frac{e^2E_0^2t^2}{m^2v_0^2}}$ (*c*) $\frac{\lambda_0}{\sqrt{1 + \frac{e^2E_0^2t^2}{m^2v_0^2}}}$ (*d*) $\frac{\lambda_0}{\left(1 + \frac{e^2E_0^2t^2}{m^2v_0^2}\right)}$

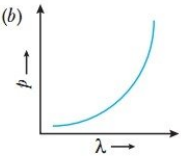
16. **Photons of energy 3.2 eV are incident on a photosensitive surface. If the stopping potential for the emitted electrons is 1.5 V, the work funtion for the surface is** **[*CBSE 2023 (55/4/1)*]**
(*a*) 1.5 eV (*b*) 1.7 eV (*c*) 3.2 eV (*d*) 4.7 eV

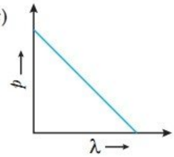
17. **A particle of mass 1 mg has the same wavelength as an electron moving with a velocity of 3×10^6 ms^{-1}. The velocity of the particle is (mass of electron = 9.1×10^{-31} kg)**

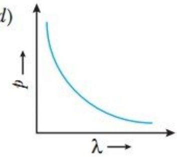
(*a*) 2.7×10^{-18} ms^{-1} (*b*) 9×10^{-2} ms^{-1} (*c*) 3×10^{-31} ms^{-1} (*d*) 2.7×10^{-21} ms^{-1}

18. **Which of the following figures represent the variation of particle momentum and the associated de Broglie wavelength?** ***[CBSE 2020 (55/5/1)]***

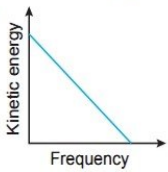
(*a*)


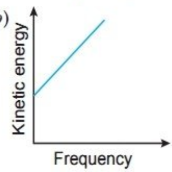
(*b*)


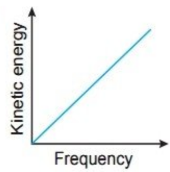
(*c*)


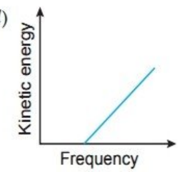
(*d*)


19. **According to Einstein's photoelectric equation, the graph between the kinetic energy of photoelectrons ejected and the frequency of incident radiation is**

(*a*)


(*b*)


(*c*)


(*d*)


20. **The kinetic energy of a proton and that of an α-particle are 4 eV and 1 eV respectively. The ratio of the de Broglie wavelengths associated with them will be** ***[CBSE 2020 (55/4/1)]***

(*a*) 2:1 (*b*) 1:1
(*c*) 1:2 (*d*) 4:1

21. **If photons of frequency ν are incident on the surfaces of two metals, *A* and *B* of threshold frequencies $\nu/2$ and $\nu/3$ respectively, the ratio of maximum kinetic energy of electrons emitted from *A* to that from *B* is** ***[CBSE 2020 (55/5/1)]***

(*a*) 2 : 3 (*b*) 3 : 4
(*c*) 1 : 3 (*d*) $\sqrt{3} : \sqrt{2}$

22. **Sodium surface is illuminated by ultraviolet and visible radiation successively and the stopping potential is determined. This stopping potential is**

(*a*) equal in both cases (*b*) more with ultraviolet light
(*c*) more with visible light (*d*) varies randomly

23. **In a photoelectric experiment, the wavelength of the incident radiation is reduced from 6000 Å to 4000 Å, while the intensity of radiation remains the same; then**

(*a*) the cut-off potential will decrease
(*b*) the cut-off potential will increase
(*c*) the photoelectric current will increase
(*d*) the kinetic energy of the emitted electrons will decrease

Answers

1. (*d*)	**2.** (*b*)	**3.** (*d*)	**4.** (*c*)	**5.** (*c*)	**6.** (*d*)	**7.** (*d*)
8. (*c*)	**9.** (*a*)	**10.** (*b*)	**11.** (*b*)	**12.** (*c*), (*d*)	**13.** (*a*)	**14.** (*b*)
15. (*c*)	**16.** (*b*)	**17.** (*a*)	**18.** (*d*)	**19.** (*d*)	**20.** (*b*)	**21.** (*b*)
22. (*b*)	**23.** (*b*)					

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(*a*) *Both A and R are true and R is the correct explanation of A.*

(*b*) *Both A and R are true but R is not the correct explanation of A.*

(*c*) *A is true but R is false.*

(*d*) *A is false and R is also false.*

1. **Assertion(*A*)** : Matter has wave-particle nature.
   Reason (*R*) : Light has dual nature.
2. **Assertion(*A*)** : In the process of photoelectric emission, all emitted electrons have the same kinetic energy.
   Reason (*R*) : According to Einstein's equation $E_k = h\nu + \phi_0$.
3. **Assertion(*A*)** : Photoelectric effect demonstrates the wave nature of light.
   Reason (*R*) : The number of photoelectrons is proportional to the velocity of incident light.
4. **Assertion(*A*)** : Photoelectric effect demonstrates the particle nature of light.
   Reason (*R*) : Photoelectric current is proportional to intensity of incident radiation for frequencies more than the threshold frequency. *[CBSE 2023 (55/1/1)]*
5. **Assertion(*A*)** : On increasing the intensity of light the photocurrent increases.
   Reason (*R*) : The photocurrent increases with increase of frequency of light.
6. **Assertion(*A*)** : Photoelectric process is instantaneous process.
   Reason (*R*) : When photons of energy ($h\nu$) greater than work function of metal (ϕ_0) are incident on a metal, the electrons from metal are emitted with no time lag.
7. **Assertion(*A*)** : Photoelectric effect demonstrates the wave nature of light. *[AIIMS 2018]*
   Reason (*R*) : The number of photoelectrons is proportional to the frequency of light.
8. **Assertion(*A*)** : If intensity of incident light is doubled, the kinetic energy of photoelectron is also doubled.
   Reason (*R*) : The kinetic energy of photoelectron is directly proportional to intensity of incident light.
9. **Assertion(*A*)** : An electron and a photon possessing same wavelength, will have the same momentum.
   Reason (*R*) : Momentum of both particle is same by de-Broglie hypothesis.
10. **Assertion(*A*)** : An electron microscope is based on de-Broglie hypothesis. *[AIIMS 2014]*
    Reason (*R*) : A beam of electrons behaves as a wave which can be converged by electric and magnetic lenses.

Answers

1. (*b*) **2.** (*d*) **3.** (*d*) **4.** (*b*) **5.** (*c*) **6.** (*a*) **7.** (*d*)
8. (*d*) **9.** (*a*) **10.** (*a*)

Case-based/Passage-based Questions

Read the paragraph given below and answer the questions that follow:

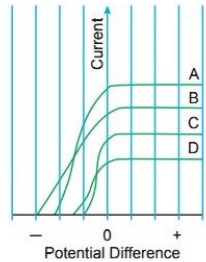


Figure shows the variation of photoelectric current measured in a photo cell circuit as a function of the potential difference between the plates of the photo cell when light beams A, B, C and D of different wavelengths are incident on the photo cell. Examine the given figure and answer the following questions: **[*CBSE 2023 (55/2/1), Modified*]**

(*i*) Which light beam has the highest frequency?

(*a*) A (*b*) B

(*c*) C (*d*) D

(*ii*) Which light beam ejects photoelectrons will maximum momentum?

(*a*) D (*b*) C (*c*) B (*d*) A

(*iii*) Consider a beam of electrons (each electrons with energy E_0) incident on a metal surface kept in an evacuated chamber then

(*a*) electrons can be emitted with any energy, with a maximum of E_0

(*b*) electrons can be emitted with any energy, with a maximum of $E_0 - \phi$, (ϕ is the work function)

(*c*) electrons can be emitted but all with an energy, E_0

(*d*) no electrons will be emitted as only photons can emit electrons

(*iv*) The stopping potential of a photocell, in which electrons with a maximum kinetic energy of 6 eV are emitted will be

(*a*) –6V (*b*) 6V (*c*) 3V (*d*) –3V

OR

Sodium and copper have work functions 2.3 eV and 4.5 eV respectively. Then the ratio of their threshold wavelengths is nearest to

(*a*) 1 : 2 (*b*) 1 : 4 (*c*) 2 : 1 (*d*) 4 : 1

Explanations

(*i*) (*b*) The light beam B, because it requires maximum retarding potential to reduce the photoelectric current to zero.

(*ii*) (*c*) The light beam B ejects photoelectrons with maximum momentum, because highest frequency light beam ejects photoelectrons with highest kinetic energy and hence highest momentum.

(*iii*) (*d*) When a beam of electrons of energy E_0 of each electron is incident on a metal surface kept in vacuum, then due to elastic collision with electrons on surface, energy of incident electrons will be transferred to the emitted electrons. To emit the electrons below the surface, a part of E_0 of incident electrons is consumed against work function. So, energy of emitted electrons becomes less than E_0. So, the maximum energy of emitted electrons can be E_0.

(*iv*) (*a*) We have, $E_k = eV_0 \Rightarrow 6\text{ eV} = eV_0 \Rightarrow V_0 = 6\text{ V}$

The stopping potential V_0= 6 volt (Negative).

(c) $W_0 = h\upsilon_0 = \dfrac{hc}{\lambda_0} \Rightarrow \lambda_0 \propto \dfrac{1}{W_0}$

$$\Rightarrow \frac{\lambda_0(\text{Na})}{\lambda_0(\text{Cu})} = \frac{W_0(\text{Cu})}{W_0(\text{Na})} = \frac{4.5}{2.3} = 2$$

$$\therefore\ \lambda_0(\text{Na}) : \lambda_0(\text{Cu}) = 2:1$$

CONCEPTUAL QUESTIONS

Q. 1. Name the phenomenon which shows the quantum nature of electromagnetic radiation.

[*CBSE (AI) 2017*]

Ans. The quantum nature of electromagnetic radiation is shown by the phenomenon of photoelectric effect.

[*Topper's Answer 2017*]

Q. 2. Define intensity of radiation on the basis of photon picture of light. Write its SI unit.

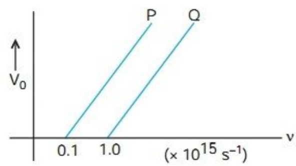
[*CBSE (AI) 2014; 2019 (55/1/1)*]

Ans. The amount of light energy or photon energy incident per metre square per second is called intensity of radiation.

SI unit: $\dfrac{\text{W}}{\text{m}^2}$ or $\text{J/s} - \text{m}^2$

Q. 3. The figure shows the variation of stopping potential V_0 with the frequency ν of the incident radiations for two photosensitive metals *P* and *Q*. Which metal has smaller threshold wavelength? Justify your answer.

[*CBSE 2019 (55/4/1)*]



Ans. Since $\lambda_0 = \dfrac{c}{\nu_0}$, metal *Q* has smaller threshold wavelength.

Q. 4. Write the basic features of photon picture of electromagnetic radiation on which Einstein's photoelectric equation is based.

[*CBSE Delhi 2013*]

Ans. Features of the photons:

(*i*) Photons are particles of light having energy $E = h\nu$ and momentum $p = \dfrac{h}{\lambda}$, where h is Planck constant.

(*ii*) Photons travel with the speed of light in vacuum, independent of the frame of reference.

(*iii*) Intensity of light depends on the number of photons crossing unit area in a unit time.

Q. 5. Define the term 'stopping potential' in relation to photoelectric effect. [*CBSE (AI) 2011*]

Ans. The minimum retarding (negative) potential of anode of a photoelectric tube for which photoelectric current stops or becomes zero is called the stopping potential.

Q. 6. Define the term 'threshold frequency' in relations to photoelectric effects.

[*CBSE (F) 2011, 2019 (55/1/1), 2020 (55/2/1)*]

Ans. The minimum frequency that an incoming photon must contain so that it can just overcome the ~~to~~ work function and start photoelectric effect is called 'threshold frequency' in photoelectric emission.

[*Topper's Answer 2020*]

Q. 7. In photoelectric effect, why should the photoelectric current increase as the intensity of monochromatic radiation incident on a photosensitive surface is increased? Explain.

[CBSE (F) 2014]

Ans. The photoelectric current increases proportionally with the increase in intensity of incident radiation. Larger the intensity of incident radiation, larger is the number of incident photons and hence larger is the number of electrons ejected from the photosensitive surface.

Q. 8. State de Broglie hypothesis. *[CBSE Delhi 2012]*

Ans. According to hypothesis of de Broglie "The atomic particles of matter moving with a given velocity, can display the wave like properties."

i.e., $\lambda = \frac{h}{mv}$ (mathematically)

Q. 9. What is the wavelength of a photon of energy 3.3×10^{-19} J? *[CBSE 2020 (55/2/1)]*

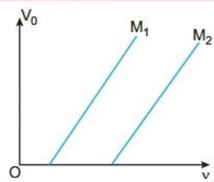
Ans. Wavelength, $\lambda = \frac{hc}{E}$. $\therefore \lambda = \frac{6.63\times10^{-34} \times 3\times10^{8}}{3.3\times10^{-19}}$ m

$= \frac{19.89}{3.3} \times 10^{-7}$ m $\approx 6.03\times10^{-7}$ m.

$\therefore$ reqd. wavelength $= 6.03\times10^{-7}$ m.

[Topper's Answer 2020]

Q. 10. The variation of the stopping potential (V_o) withe the frequency (ν) of the light incident on two different photosensitive surfaces M_1 and M_2 is shown in the figure. Identify the surface which has greater value of the work function. *[CBSE 2020 (55/1/1)]*

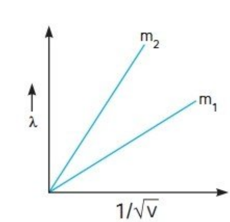


Ans. M_2 has greater value of work function due to higher value of threshold frequency.

Q. 11. Plot a graph showing variation of de Broglie wavelength λ versus $\frac{1}{\sqrt{V}}$, where V is accelerating potential for two particles A and B carrying same charge but of masses m_1, m_2 ($m_1 > m_2$). Which one of the two represents a particle of smaller mass and why? *[CBSE Delhi 2016] [HOTS]*

Ans. As, $\lambda = \frac{h}{\sqrt{2mqV}}$ or $\lambda = \left(\frac{h}{\sqrt{2q}} . \frac{1}{\sqrt{m}}\right)\frac{1}{\sqrt{V}}$

or $\frac{\lambda}{\frac{1}{\sqrt{V}}} = \frac{h}{\sqrt{2q}} . \frac{1}{\sqrt{m}}$



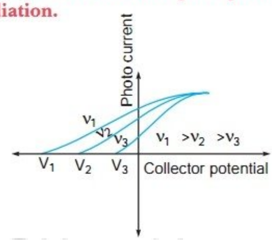
As the charge on two particles is same, we get

Slope $\propto \frac{1}{\sqrt{m}}$

Hence, particle with lower mass (m_2) will have greater slope.

Q. 12. Show the variation of photocurrent with collector plate potential for different frequencies but same intensity of incident radiation. *[CBSE (F) 2011] [HOTS]*

Ans.



Q. 13. (a) Define the term 'intensity of radiation' in photon picture.

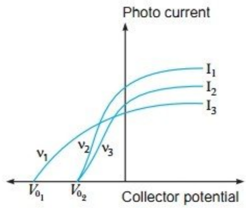
(b) Plot a graph showing the variation of photo current vs collector potential for three different intensities $I_1 > I_2 > I_3$, two of which (I_1 and I_2) have the same frequency ν and the third has frequency $\nu_1 > \nu$.

(c) Explain the nature of the curves on the basis of Einstein's equation.

[CBSE South 2016] *[HOTS]*

Ans. (a) The amount of light energy or photon energy incident per metre square per second is called intensity of radiation.

(b) $\nu_2 = \nu_3 = \nu$



(c) As per Einstein's equation,

(i) The stopping potential is same for I_1 and I_2 as they have the same frequency.

(ii) The saturation currents are as shown in figure because $I_1 > I_2 > I_3$.

Q. 14. Two metals *A* and *B* have work functions 4 eV and 10 eV respectively. Which metal has the higher threshold wavelength?

Ans. Work function $W = h\nu_0 = \dfrac{hc}{\lambda_0}$

$\Rightarrow \qquad \lambda_0 \propto \dfrac{1}{W}$

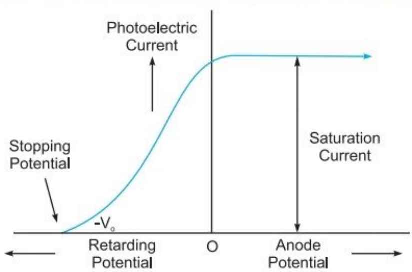
As $\qquad W_A < W_B;\ (\lambda_0)_A > (\lambda_0)_B$

i.e., threshold wavelength of metal *A* is higher.

Q. 15. (a) Draw a graph showing variation of photocurrent with anode potential for a particular intensity of incident radiation. Mark saturation current and stopping potential.

(b) How much would stopping potential for a given photosensitive surface go up if the frequency of the incident radiations were to be increased from 4×10^{15} Hz to 8×10^{15} Hz?

Ans. (a)



Intercept of the graph with potential axis gives the stopping potential.

(b) We have, $\quad h\nu_{in} = eV_O$

$\Rightarrow \qquad V_O = \dfrac{h(\nu_2 - \nu_1)}{e}$

$$= \frac{6.62 \times 10^{-34} \times (8 \times 10^{15} - 4 \times 10^{15})}{1.6 \times 10^{-19}}$$

$$= \frac{6.62 \times 4 \times 10^{15} \times 10^{-34}}{1.6 \times 10^{-19}} \text{V}$$

$$\mathbf{= 16.55\ V}$$

Q. 16. There are materials which absorb photons of shorter wavelength and emit photons of longer wavelength. Can there be stable substances which absorb photons of larger wavelength and emit light of shorter wavelength? **[*NCERT Exemplar*]**

Ans. In the first case, energy given out is less than the energy supplied. In the second case, the material has to supply the energy as the emitted photon has more energy. This cannot happen for stable substances.

Q. 17. Do all the electrons that absorb a photon come out as photoelectrons? **[*NCERT Exemplar*] [*HOTS*]**

Ans. No, most electrons get scattered into the metal. Only a few come out of the surface of the metal.

Q. 18. Electrons are emitted from a photosensitive surface when it is illuminated by green light but electron emission does not take place by yellow light. Will the electrons be emitted when the surface is illuminated by (*i*) red light, and (*ii*) blue light? **[*HOTS*]**

Ans. (*i*) No (*ii*) Yes.

Reason: According to colour sequence VIBGYOR, the frequency of red light photons is less than threshold frequency of photometal but frequency of blue light photons is more than threshold frequency of photometal; so (*i*) electrons will not be emitted by red light and (*ii*) electrons will be emitted by blue light.

Q. 19. In a photoelectric effect, the yellow light is just able to emit electrons, will green light emit photoelectrons? What about red light? **[*HOTS*]**

Ans. Energy of photon $E = \frac{hc}{\lambda} \propto \frac{1}{\lambda}$

As $\lambda_{green} < \lambda_{yellow}$ so green light photon has more energy than yellow light photon, so green light will eject electron.

As $\lambda_{red} > \lambda_{yellow}$ so red light photon has lesser energy than yellow light photon, so red light will not be able to eject electrons.

Q. 20. The photoelectric cut-off voltage in a certain photoelectric experiment is 1.5 V. What is the maximum kinetic energy of photoelectrons emitted? **[*NCERT*]**

Ans. Cut-off voltage, $V_0 = 1.5$ V

Maximum kinetic energy of photoelectrons

$$E_k = eV_0 = 1.5 \text{ eV} = 1.5 \times 1.6 \times 10^{-19} \text{ J} = \mathbf{2.4 \times 10^{-19}\ J}$$

Very Short Answer Questions

Each of the following questions are of 2 marks.

Q. 1. Write Einstein's photoelectric equation and point out any two characteristic properties of photons on which this equation is based. **[*CBSE (AI) 2013*]**

Ans. If radiation of frequency (ν) greater than threshold frequency (ν_0) irradiate the metal surface, electrons are emitted out from the metal. So Einstein's photoelectric equation can be given as

$$K_{max} = \frac{1}{2}mv_{max}^2 = h\nu - h\nu_0$$

Characteristic properties of photons:

(*i*) Energy of photon is directly proportional to the frequency (or inversely proportional to the wavelength).

(*ii*) In photon-electron collision, total energy and momentum of the system of two constituents remains constant.

(*iii*) In the interaction of photons with the free electrons, the entire energy of photon is absorbed.

Q. 2. Write three characteristic features in photoelectric effect which cannot be explained on the basis of wave theory of light, but can be explained only using Einstein's equation.

[*CBSE Delhi 2016*]

Ans. The three characteristic features which cannot be explained by wave theory are:

(*i*) Kinetic energy of emitted electrons is found to be independent of the intensity of incident light.

(*ii*) There is no emission of electrons if frequency of incident light is below a certain frequency (threshold frequency).

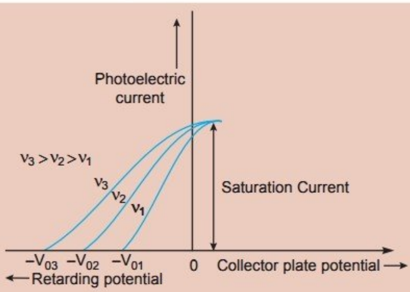
(*iii*) Photoelectric effect is an instantaneous process.

Q. 3. Plot suitable graphs to show the variation of photoelectric current with the collector plate potential for the incident radiation of **[*CBSE 2022 (55/1/1), Term-2*]**

(*i*) the same intensity but different frequencies ν_1, ν_2 and ν_3 ($\nu_1 < \nu_2 < \nu_3$)

(*ii*) the same frequency but different intensities I_1, I_2 and I_3 ($I_1 < I_2 < I_3$)

Ans.



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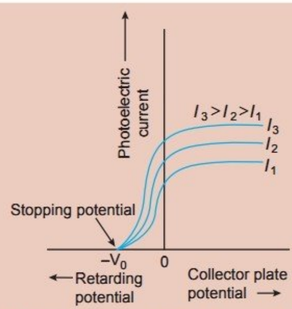

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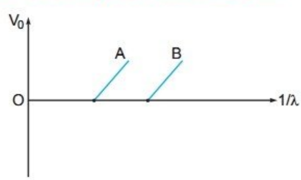
[*CBSE Marking Scheme 2022 (55/1/1), Term-2*]

Q. 4. Figure shows the stopping potential (V_0) for the photo electron versus ($1/\lambda$) graph, for two metals *A* and *B*, λ being the wavelength of incident light.



(*a*) How is the value of Planck's constant determined from the graph?

(*b*) If the distance between the light source and the surface of metal *A* is increased, how will the stopping potential for the electrons emitted from it be effected? Justify your answer.

[*CBSE 2020 (55/5/1)*]

Ans. According to Einstein's Photo-electric equation,

$$h\nu = \phi_0 + eV_s$$

$$\Rightarrow \quad eV_s = h\nu - \phi_0$$

$$\therefore \quad V_s = \frac{h\nu}{e} - \frac{\phi_o}{e}$$ ½

Since $\nu = c / \lambda$

$$\therefore V_s = \frac{h\nu}{e\lambda} - \frac{\phi_0}{e}$$

$$= \left(\frac{hc}{e}\right)\frac{1}{\lambda} + \left[\frac{-\phi_0}{e}\right]$$

Comparing with the equation of straight line $y = mx + c$

(*a*) The slope of the line $m = \frac{hc}{e}$. Hence, Planck's constant $h = \frac{me}{c}$ ½

(*b*) Stopping potential will remain same. ½

Justification

Variation of distance of light source from the metal surface will alter the intensity while the stopping potential however depends only on the frequency and not on the intensity of the incident light. ½

[CBSE Marking Scheme 2022 (55/5/1)]

Q. 5. Monochromatic light of frequency 6×10^{14} Hz is produced by a laser. The power emitted is 2.0×10^{-3} W. How many photons per second on an average are emitted by the source?

[CBSE Guwahati 2015]

Ans. Power of radiation, $P = \frac{nh\nu}{t} = Nh\nu$, where N is number of photons per sec.

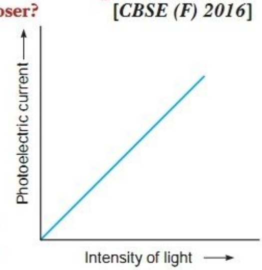
or $$N = \frac{P}{h\nu} = \frac{2.0 \times 10^{-3}}{6.63 \times 10^{-34} \times 6 \times 10^{14}}$$

$$= \mathbf{5 \times 10^{15}} \text{ photons per second}$$

Q. 6. Plot a graph showing the variation of photoelectric current with intensity of light. The work function for the following metals is given:

Na: 2.75 eV and Mo: 4.175 eV.

Which of these will not give photoelectron emission from a radiation of wavelength 3300 Å from a laser beam? What happens if the source of laser beam is brought closer? *[CBSE (F) 2016]*



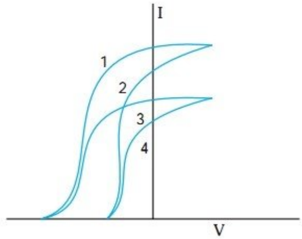
Ans. Energy of photon $E = \frac{hc}{\lambda}$ joule

$$= \frac{hc}{e\lambda}\text{eV}$$

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-19} \times 3.3 \times 10^{-7}} \text{eV} = \mathbf{3.76 \text{ eV}}$$

Since W_0 of Mo is greater than E, $\therefore$ Mo will not give photoemission. There will be no effect of bringing source closer in the case of Mo. In case of Na, photocurrent will increase.

Q. 7. The given graph shows the variation of photo-electric current (*I*) with the applied voltage (*V*) for two different materials and for two different intensities of the incident radiations. Identify and explain using Einstein's photo electric equation for the pair of curves that correspond to (*i*) different materials but same intensity of incident radiation, (*ii*) different intensities but same materials. *[CBSE East 2016]*



Ans. (*i*) (*a*) 1 and 2 correspond to same intensity but different material.

(*b*) 3 and 4 correspond to same intensity but different material.

This is because the saturation currents are same and stopping potentials are different.

(*ii*) (*a*) 1 and 3 correspond to different intensity but same material.

(*b*) 2 and 4 correspond to different intensity but same material.

This is because the stopping potentials are same but saturation currents are different.

Q. 8. Light of wavelength 488 nm is produced by an Argon Laser which is used in the photoelectric effect. When light from this spectral line is incident on the cathode the stopping potential of photoelectrons is 0.38 V. Find the work function of the cathode material. **[*NCERT*]**

Ans. Given $\lambda = 488$ nm $= 488 \times 10^{-9}$ m, $V_0 = 0.38$ V,

Energy of incident photon, $E = \dfrac{hc}{\lambda}$

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{488 \times 10^{-9}} = 4.08 \times 10^{-19}\,\text{J}$$

$$= \frac{4.08 \times 10^{-19}}{1.6 \times 10^{-19}} = 2.55\,\text{eV}$$

From Einstein's photoelectric equation, $\dfrac{hc}{\lambda} = \phi_0 + eV_0$

Work function, $\phi_0 = \dfrac{hc}{\lambda} - eV_0 = 2.55\,\text{eV} - 0.38\,\text{eV} = \mathbf{2.17\,eV}$

Q. 9. If the frequency of light incident on the cathode of a photo-cell is increased, how will the following be affected? Justify your answer.

(*i*) Energy of the photo electrons

(*ii*) Photo current **[*CBSE 2020 (55/4/1)*]**

Ans. (*i*) The energy of the emitted photoelectrons increases ½

As $E_k = h\nu - \phi_0$

As ν increases, E_k also increases. ½

(*ii*) Photo current will not be affected. ½

As, increase of ν E_k will increase but not the number of photoelectorns. ½

[Alternatively photocurrent depends upon intensity of light and not on frequency]

[*CBSE Marking Scheme 2020 (55/4/1)*]

Q. 10. An electromagnetic wave of wavelength λ_1 is incident on a photosensitive surface of negligible work function. If the photo-electrons emitted from this surface have the de Broglie wavelength prove that $\lambda = \left(\dfrac{2mc}{h}\right)\lambda_1^2$ **[*CBSE Delhi 2008*]**

Ans. Kinetic energy of electrons, E_k = energy of photon of EM wave

$$= \frac{hc}{\lambda} \quad \ldots(i)$$

de Broglie wavelength, $\lambda_1 = \frac{h}{\sqrt{2mE_k}}$ or $\lambda_1^2 = \frac{h^2}{2mE_k}$

Using (*i*), we get

$$\lambda_1^2 = \frac{h^2}{2m\left(\frac{hc}{\lambda}\right)} \quad \Rightarrow \quad \lambda = \left(\frac{2mc}{h}\right)\lambda_1^2$$

Q. 11. The de Broglie wavelengths associated with an electron and a proton are equal. Prove that the kinetic energy of the electron is greater than that of the proton. [*CBSE 2020 (55/3/2)*]

Ans. As from de Broglie wavelength,

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE_k}} \quad \frac{1}{2} + \frac{1}{2}$$

where E_k = kinetic energy

for equal λ,

$$E_k \propto \frac{1}{mass}$$

mass of electron < mass of proton ½

$\therefore$ Kinetic Energy of electron is more than kinetic energy of proton ½

[*CBSE Marking Scheme 2020 (55/3/2)*]

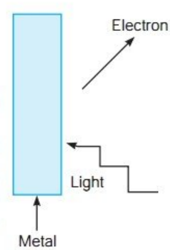
Q. 12. There are two sources of light, each emitting with a power 100 W. One emits *X*-rays of wavelength 1 nm and the other visible light at 500 nm. Find the ratio of number of photons of *X*-rays the photons of visible light of the given wavelength. [*NCERT Exemplar*]

Ans. Total E is constant.

Let n_1 and n_2 be the number of photons of *X*-rays and visible region.

$$n_1 E_1 = n_2 E_2 \quad \Rightarrow \quad n_1 \frac{hc}{\lambda_1} = n_2 \frac{hc}{\lambda_2}$$

$$\therefore \frac{n_1}{n_2} = \frac{\lambda_1}{\lambda_2} = \mathbf{\frac{1}{500}}$$



Q. 13. Consider Fig. for photoemission.

How would you reconcile with momentum-conservation? No light (Photons) have momentum in a different direction than the emitted electrons. [*NCERT Exemplar*]

Ans. The momentum is transferred to the metal. At the microscopic level, atoms absorb the photon and its momentum is transferred mainly to the nucleus and electrons. The excited electron is emitted. Conservation of momentum needs to be accounted for the momentum transferred to the nucleus and electrons.

Q. 14. A photon and a proton have the same de Broglie wavelength λ. Prove that the energy of the photon is $(2m\lambda c/h)$ times the kinetic energy of the proton. [*CBSE 2019 (55/2/1)*]

Ans. Energy of photon $E_P = \frac{hc}{\lambda}$ ...(*i*)

For proton $\lambda = \frac{h}{mv}$

$$mv = \frac{h}{\lambda}$$

Kinetic energy of proton, $E_k = \frac{1}{2}mv^2$

$$E_k = \frac{1}{2}\frac{h^2}{m\lambda^2}$$

From equation (*i*), we get,

$$E_P = \left(\frac{2m\lambda c}{h}\right)E_k$$

Q. 15. If light of wavelength 412.5 nm is incident on each of the metals given below, which ones will show photoelectric emission and why? [*CBSE 2018*]

Metal	Work Function (eV)
Na	1.92
K	2.15
Ca	3.20
Mo	4.17

Ans. The energy of the incident photon,

$$E = h\nu = \frac{hc}{\lambda}$$

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{412.5 \times 10^{-9}} \text{ J}$$

$$= \frac{0.048 \times 10^{-17}}{1.6 \times 10^{-19}} \text{ eV } = \mathbf{3 \text{ eV}}$$

Metals having work function less than energy of the incident photon will show photoelectric effect. Hence, only Na and K will show photoelectric emission.

CONSTRUCTED RESPONSE QUESTIONS AS PER NEP

Short Answer Questions

Each of the following questions are of 3 marks.

Q. 1. Explain briefly the reasons why wave theory of light is not able to explain the observed features of photo-electric effect. [*CBSE Delhi 2013; (AI) 2013; (F) 2010; 2019 (55/2/1)*]

Ans. The observed characteristics of photoelectric effect could not be explained on the basis of wave theory of light due to the following reasons.

(*i*) According to wave theory, the light propagates in the form of wavefronts and the energy is distributed uniformly over the wavefronts. With increase of intensity of light, the amplitude of waves and the energy stored by waves will increase. These waves will then, provide more energy to electrons of metal; consequently, the energy of electrons will increase.

Thus, ***according to wave theory, the kinetic energy of photoelectrons must depend on the intensity of incident light; but according to experimental observations, the kinetic energy of photoelectrons does not depend on the intensity of incident light.***

(*ii*) According to wave theory, the light of any frequency can emit electrons from metallic surface provided the intensity of light be sufficient to provide necessary energy for emission of electrons, but according to experimental observations, the light of frequency less than threshold frequency cannot emit electrons; whatever the intensity of incident light may be.

(*iii*) According to wave theory, the energy transferred by light waves will not go to a particular electron, but it will be distributed uniformly to all electrons present in the illuminated surface. Therefore, electrons will take some time to collect the necessary energy for their emission. The time for emission will be more for light of less intensity and vice versa. But experimental observations show that the emission of electrons take place instantaneously after the light is incident on the metal; whatever the intensity of light may be.

Q. 2. Write Einstein's photoelectric equation. State clearly the three salient features observed in photoelectric effect which can explain on the basis of this equation. ***[CBSE 2023 (55/1/1)]***

The maximum kinetic energy of the photoelectrons gets doubled when the wavelength of light incident on the surface changes from λ_1 to λ_2. Derive the expressions for the threshold wavelength λ_0 and work function for the metal surface.

[CBSE Delhi 2015; (AI) 2010; 2020 (55/2/1)]

Ans. Einstein's photoelectric equation:

$$h\nu = h\nu_0 + eV_0$$

where ν = incident frequency, ν_0 = threshold frequency, V_0 = stopping potential

(*i*) Incident energy of photon is used in two ways (*a*) to liberate electron from the metal surface (*b*) rest of the energy appears as maximum energy of electron.

(*ii*) Only one electron can absorb energy of one photon. Hence increasing intensity increases the number of electrons hence current.

(*iii*) If incident energy is less than work function, no emission of electron will take place.

(*iv*) Increasing ν (incident frequency) will increase maximum kinetic energy of electrons but number of electrons emitted will remain same.

For wavelength λ_1,

$$\frac{hc}{\lambda_1} = \phi_0 + K = \phi_0 + eV_0 \quad \text{where } K = eV_0 \qquad \ldots(i)$$

For wavelength λ_2,

$$\frac{hc}{\lambda_2} = \phi_0 + 2eV_0 \qquad \ldots(ii)$$

From equation (*i*) and (*ii*), we get

$$\frac{hc}{\lambda_2} = \phi_0 + 2\left(\frac{hc}{\lambda_1} - \phi_0\right) = \phi_0 + \frac{2hc}{\lambda_1} - 2\phi_0$$

$$\Rightarrow \qquad \phi_0 = \frac{2hc}{\lambda_1} - \frac{hc}{\lambda_2}$$

For threshold wavelength λ_0 kinetic energy, $K = 0$, and work function $\phi_0 = \frac{hc}{\lambda_0}$

$$\therefore \qquad \frac{hc}{\lambda_0} = \frac{2hc}{\lambda_1} - \frac{hc}{\lambda_2}$$

$$\Rightarrow \qquad \frac{1}{\lambda_0} = \frac{2}{\lambda_1} - \frac{1}{\lambda_2} \quad \Rightarrow \quad \lambda_0 = \frac{\lambda_1\lambda_2}{2\lambda_2 - \lambda_1}$$

Work function, $\phi_0 = \dfrac{hc(2\lambda_2 - \lambda_1)}{\lambda_1\lambda_2}$

Q. 3. Using photon picture of light, show how Einstein's photoelectric equation can be established. Write two features of photoelectric effect which cannot be explained by wave theory.

[CBSE (AI) 2017]

Ans. In the photon picture, energy of the light is assumed to be in the form of photons each carrying energy.

When a photon of energy '$h\nu$' falls on a metal surface, the energy of the photon is absorbed by the electrons and is used in the following two ways:

(*i*) A part of energy is used to overcome the surface barrier and come out of the metal surface. This part of energy is known as a work function and is expressed as $\phi_0 = h\nu_0$.

(*ii*) The remaining part of energy is used in giving a velocity 'v' to the emitted photoelectron which is equal to the maximum kinetic energy of photo electrons $\left(\frac{1}{2}mv_{max}^2\right)$.

(*iii*) According to the law of conservation of energy,

$$h\nu = \phi_0 + \frac{1}{2}mv_{max}^2$$

$$\Rightarrow \quad h\nu = h\nu_0 + \frac{1}{2}mv_{max}^2 \quad \Rightarrow \quad h\nu = h\nu_0 + KE_{max}$$

$$\Rightarrow \quad KE_{max} = h\nu - h\nu_0$$

$$\text{or} \quad KE_{max} = h\nu - \phi_0$$

This equation is called Einstein photoelectric equation.

Features which cannot be explained by wave theory:

(*i*) The process of photoelectric emission is instantaneous in nature.

(*ii*) There exists a 'threshold frequency' for each photosensitive material.

(*iii*) Maximum kinetic energy of emitted electrons is independent of the intensity of incident light.

Q. 4. Calculate the wavelength of de Broglie waves associated with a proton having $\left(\frac{500}{1.673}\right)$ eV energy. How will the wavelength be affected for an alpha particle having the same energy.

[*CBSE 2023 (55/3/1)*]

Ans. From the de Broglie wave length,

$$\lambda_P = \frac{h}{p} = \frac{h}{\sqrt{2m_P KE}}$$

$$\text{Given, } KE \text{ of proton} = \left(\frac{500}{1.673}eV\right)$$

$$= \frac{500}{1.673} \times 1.6 \times 10^{-19}\,\text{J}$$

$$= 4.78 \times 10^{-17}\,\text{J}$$

$$\text{Wave length of proton, } \lambda_P = \frac{6.6 \times 10^{-34}}{\sqrt{2 \times 1.67 \times 10^{-27} \times 4.78 \times 10^{-17}}}$$

$$= \frac{6.6 \times 10^{-34}}{4 \times 10^{-22}} = 1.65 \times 10^{-12}\,\text{m}$$

$$\text{For } \alpha\text{-particle, } \lambda_\alpha = \frac{h}{\sqrt{2m_\alpha KE}} \qquad [K.E = \text{constant (given)}]$$

$$\Rightarrow \quad \frac{\lambda_P}{\lambda_\alpha} = \sqrt{\frac{m_\alpha}{m_P}} = \sqrt{\frac{4m_P}{m_P}} = 2$$

$$\therefore \quad \lambda_\alpha = \frac{1}{2}\lambda_P = \frac{1}{2} \times 1.65 \times 10^{-12} = 0.825 \times 10^{-12}\,\text{m}$$

Hence, wavelength for α–particle becomes half of proton's wavelength.

Q. 5. The work function of a metal is 2.31 eV. Photoelectric emission occurs when light of frequency 6.4×10^{14} Hz is incident on the metal surface. Calculate : (*i*) the energy of the incident radiation, (*ii*) the maximum kinetic energy of the emitted electron and (*iii*) the stopping potential of the surface. **[*CBSE 2022 (55/3/3), Term-2*]**

Ans.

Given frequency of light = 6.4×10^{14} Hz

Hence $\boxed{\text{energy of incident radiation} = h\nu}$

h = Planck's constant = 6.63×10^{-34} J-s

ν → frequency of incident light

→ Energy = $6.63 \times 10^{-34} \times 6.4 \times 10^{14}$ J

$= \dfrac{6.63 \times 10^{-34} \times 6.4 \times 10^{14}}{1.6 \times 10^{-19}}$ eV [∵ 1 eV = 1.6×10^{-19} J]

$= \dfrac{26.52}{10} = 2.652$ eV

Ans. Thus energy of incident radiation = 2.652 eV

From photoelectric equation

$\boxed{K_{max} = E - \phi}$

K_{max} → maximum kinetic energy of electrons

E → energy of incident radiation (= 2.652 eV)

ϕ → Work function of metal (= 2.31 eV)

→ $K_{max} = (2.652 - 2.31)$ eV

→ $\boxed{K_{max} = 0.342 \text{ eV}}$

Ans. Thus, maximum kinetic energy of emitted electrons is 0.342 eV

Stopping potential of surface = $\dfrac{K_{max}}{e}$ [e → charge of electron]

$= \dfrac{0.342 \text{ eV}}{e}$

$= \boxed{0.342 \text{ V}}$

Ans. Thus, stopping potential of the surface is 0.342 V

[*Topper's Answer 2022*]

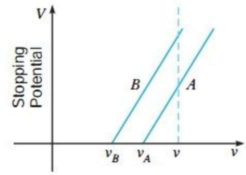
Q. 6. Sketch the graphs showing variation of stopping potential with frequency of incident radiations for two photosensitive materials A and B having threshold frequencies $\nu_A > \nu_B$.

(i) In which case is the stopping potential more and why?

(ii) Does the slope of the graph depend on the nature of the material used? Explain.

[*CBSE Central 2016*]

Ans. (i) From the graph for the same value of 'ν', stopping potential is more for material 'B'.



From Einstein's photoelectric equation,

$$eV_0 = h\nu - h\nu_0$$

$$\Rightarrow \quad V_0 = \frac{h}{e}\nu - \frac{h}{e}\nu_0 = \frac{h}{e}(\nu - \nu_0)$$

$\therefore$ V_0 is higher for lower value of ν_0

(ii) No, as slope is given by $\frac{h}{e}$ which is a universal constant.

Q. 7. A beam of monochromatic radiation is incident on a photosensitive surface. Answer the following questions giving reasons:

(i) Do the emitted photoelectrons have the same kinetic energy?

(ii) Does the kinetic energy of the emitted electrons depend on the intensity of incident radiation?

(iii) On what factors does the number of emitted photoelectrons depend? **[*CBSE (F) 2015*]**

Ans. In photoelectric effect, an electron absorbs a quantum of energy $h\nu$ of radiation, which exceeds the work function, an electron is emitted with maximum kinetic energy,

$$K_{max} = h\nu - W$$

(i) No, all electrons are bound with different forces in different layers of the metal. So, more tightly bound electron will emerge with less kinetic energy. Hence, all electrons do not have same kinetic energy.

(ii) No, because an electron cannot emit out if quantum energy $h\nu$ is less than the work function of the metal. The $K.E.$ depends on energy of each photon.

(iii) Number of emitted photoelectrons depends on the intensity of the radiations provided the quantum energy $h\nu$ is greater than the work function of the metal.

Q. 8. Why are de Broglie waves associated with a moving football not visible?

The wavelength 'λ' of a photon and the de Broglie wavelength of an electron have the same value. Show that the energy of photon is $\frac{2\lambda mc}{h}$ times the kinetic energy of electron, where m, c, h have their usual meanings. **[*CBSE (F) 2016*]**

Ans. Due to large mass of a football the de Broglie wavelength associated with a moving football is much smaller than its dimensions, so its wave nature is not visible.

de Broglie wavelength of electron $\lambda = \frac{h}{mv} \Rightarrow v = \frac{h}{m\lambda}$ ....(i)

energy of photon $E = \frac{hc}{\lambda}$ (because λ is same)

Ratio of energy of photon and kinetic energy of electrons

$$\frac{E}{E_k} = \frac{hc/\lambda}{\frac{1}{2}mv^2} = \frac{2hc}{\lambda mv^2}$$

Substituting value of v from (i), we get

$$\frac{E}{E_k} = \frac{2hc}{\lambda m\,(h/m\lambda)^2} = \frac{2\lambda mc}{h}$$

$\therefore$ Energy of photon $= \frac{2\lambda mc}{h} \times$ kinetic energy of electron

Q. 9. Find the ratio of the de Broglie wavelengths associated with an alpha particle and a proton, if both

(a) have the same speeds,

(b) have the same kinetic energy,

(c) are accelerated through the same potential difference. *[CBSE 2022 (55/2/1), Term-2]*

Ans. (a) As from de Broglie wave length,

$$\lambda = \frac{h}{p} \qquad [v = \text{Same}] \qquad ½$$

$$\frac{\lambda_\alpha}{\lambda_\alpha} = \frac{h}{m_\alpha v_\alpha} \times \frac{m_p v_p}{h} = \frac{1}{4} \qquad ½$$

(b) We know, $p = \sqrt{2m\,(K.E)}$ $\qquad [K.E = \text{Same}]$ $\qquad ½$

$$\frac{\lambda_\alpha}{\lambda_p} = \frac{h}{\sqrt{2m_\alpha (K.E.)_\alpha}} \times \frac{\sqrt{2m_p (K.E.)_p}}{h} = \sqrt{\frac{m_p}{m_\alpha}} = \frac{1}{2} \qquad ½$$

(c) And $v = \sqrt{\dfrac{2qV}{m}}$ $\qquad [V = \text{Same}]$ $\qquad ½$

$$\frac{\lambda_\alpha}{\lambda_p} = \frac{h}{m_\alpha v_\alpha} \times \frac{m_p v_p}{h} = \frac{m_p}{m_a}\sqrt{\frac{2q_p V}{m_p}} \times \sqrt{\frac{m_\alpha}{2q_\alpha V}}$$

$$= \frac{m_p}{m_\alpha}\sqrt{\frac{m_\alpha}{m_p}} \times \sqrt{\frac{q_p}{q_\alpha}} = \frac{1}{2\sqrt{2}} \qquad ½$$

[CBSE Marking Scheme 2022 (55/2/1), Term-2]

Q. 10. The work function of caesium metal is 2.14 eV. When light of frequency 6×10^{14} Hz is incident on the metal surface, photoemission of electrons occurs. What is the *[NCERT]*

(a) maximum kinetic energy of the emitted electrons?

(b) stopping potential and (c) maximum speed of emitted electrons?

Ans. Given $\phi_0 = 2.14$ eV, $\nu = 6\times10^{-14}$ Hz

(a) Maximum kinetic energy of emitted electron,

$$E_k = h\nu - \phi_0 = 6.63 \times 10^{-34} \times 6 \times 10^{14} - 2.14 \times 1.6 \times 10^{-19}$$

$$= 0.554 \times 10^{-19}\ \text{J} = \frac{0.554 \times 10^{-19}}{1.6 \times 10^{-19}}\ \text{eV} = \mathbf{0.34\ eV}$$

(b) Stopping potential V_0 is given by

$$E_k = eV_0 \Rightarrow V_0 = \frac{E_k}{e} = \frac{0.34\ \text{eV}}{e} = \mathbf{0.34\ V}$$

(c) Maximum speed ($v_{\max}$) of emitted electrons is given by

$$\frac{1}{2} m v_{\max}^2 = E_k$$

or $$v_{\max} = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2 \times 0.554 \times 10^{-19}}{9.1 \times 10^{-31}}} = \mathbf{3.48\times10^5\ m/s}$$

Q. 11. (a) Explain de Broglie argument to propose his hypothesis. Show that de Broglie wavelength of photon equals electromagnetic radiation.

(b) If deuterons and alpha particle are accelerated through same potential, find the ratio of the associated de Broglie wavelengths of two. *[CBSE Sample Paper 2021]*

Ans. (*a*) Light exhibits particle aspects in certain phenomena (*e.g.*, photoelectric effect, emission and absorption of radiation), while wave aspects in other phenomena (*e.g.*, interference, diffraction and polarisation). That is, light has dual nature. In analogy with dual nature of light, de Broglie thought in terms of dual nature of matter.

Louis de Broglie postulated that the **material particles** (*e.g.*, electrons, protons, α-particles, atoms, etc.) may exhibit wave aspect. Accordingly, a moving material particle behaves as wave and the wavelength associated with material particle is

$\lambda = \frac{h}{p}$, where p is momentum. ...(*i*)

Momentum of photon of frequency ν is given as $p = \frac{h\nu}{c}$

Equation (*i*) becomes

$$\lambda = \frac{h}{\frac{h\nu}{c}} = \frac{c}{\nu}$$

$\therefore$ The wavelength of photon is equal to the wavelength of electromagnetic wave.

(*b*) From de Broglie hypothesis, $\lambda = \frac{h}{\sqrt{2mK}} = \frac{h}{\sqrt{2meV}}$

$$\frac{\lambda_d}{\lambda_\alpha} = \frac{h}{h}\frac{\sqrt{2m_\alpha 2eV}}{\sqrt{2m_d eV}} = \frac{\sqrt{2\times m_\alpha}}{\sqrt{m_d}} = \frac{\sqrt{2\times 4m_p}}{\sqrt{2m_p}} = \frac{\sqrt{4}}{1} = \frac{2}{1}$$

$\therefore$ $\lambda_d : \lambda_\alpha$ **= 2 : 1**

Q 12. Determine the value of the de Broglie wavelength associated with the electron orbiting in the ground state of hydrogen atom (Given $E_n = -(13.6/n^2)$ eV and Bohr radius $r_0 = 0.53$ Å). How will the de Broglie wavelength change when it is in the first excited state? **[*CBSE Bhubaneshwar 2015*]**

Ans. In ground state, the kinetic energy of the electron is

$$K = -E = \frac{+13.6\text{ eV}}{1^2} = 13.6\times 1.6\times 10^{-19}\text{ J} = 2.18\times 10^{-18}\text{ J}$$

de Broglie wavelength, $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mK}}$

$$= \frac{6.63\times 10^{-34}}{\sqrt{2\times 9.1\times 10^{-31}\times 2.18\times 10^{-18}}}$$

$$= 0.33\times 10^{-9}\text{ m} = 0.33\text{ nm}$$

Kinetic energy in the first excited state ($n=2$)

$$K = -E = +\frac{13.6}{2^2}\text{ eV} = +3.4\text{ eV} = 3.4\times 1.6\times 10^{-19}\text{ J} = 0.54\times 10^{-18}\text{ J}$$

de Broglie wavelength, $\lambda' = \frac{h}{\sqrt{2mK}}$

$$= \frac{6.63\times 10^{-34}}{\sqrt{2\times 9.1\times 10^{-31}\times 0.544\times 10^{-18}}}$$

$$= 2\times 0.33\text{ nm} = \mathbf{0.66\text{ nm}}$$

i.e., de Broglie wavelength will increase (or double).

Q. 13. Photoelectrons are emitted from a metal surface when illuminated with UV light of wavelength 330 nm. The minimum amount of energy required to emit the electrons from the surface is 3.5×10^{-19} J. Calculate : **[*CBSE 2022 (55/1/1), Term-2*]**

(*i*) the energy of the incident radiation, and

(*ii*) the kinetic energy of the photoelectron.

Ans. (*i*) Energy of incident radiation,

$$E = h\nu = h\frac{c}{\lambda} \quad \text{½}$$

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{330 \times 10^{-9}} \quad \text{½}$$

$$= 6.027 \times 10^{-19}\ \text{J} \quad \text{½}$$

(*ii*) Kinetic energy of photoelectron,

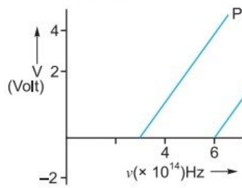
$$K.E. = E - \phi_0 \quad \text{½}$$

$$= (6.027 \times 10^{-19} - 3.5 \times 10^{-19})\text{J} \quad \text{½}$$

$$= 2.527 \times 10^{-19}\text{J} \quad \text{½}$$

[*CBSE Marking Scheme 2022 (55/1/1), Term-2*]

Q. 14. In the study of a photoelectric effect the graph between the stopping potential *V* and frequency ν of the incident radiation on two different metals *P* and *Q* is shown below:



(*i*) Which one of the two metals has higher threshold frequency?

(*ii*) Determine the work function of the metal which has greater value.

(*iii*) Find the maximum kinetic energy of electron emitted by light of frequency 8×10^{14} Hz for this metal. **[*CBSE Delhi 2017*]**

Ans. (*i*) Threshold frequency of *P* is 3×10^{14} Hz.

Threshold frequency of *Q* is 6×10^{14} Hz.

Clearly *Q* has higher threshold frequency.

(*ii*) Work function of metal *Q*, $\phi_0 = h\nu_0$

$$= (6.6 \times 10^{-34}) \times 6 \times 10^{14}\ \text{J}$$

$$= \frac{39.6 \times 10^{-20}}{1.6 \times 10^{-19}}\text{eV} = \mathbf{2.5\ eV}$$

(*iii*) Maximum kinetic energy, $K_{max} = h\nu - h\nu_0$

$$= h(\nu - \nu_0)$$

$$= 6.6 \times 10^{-34}\,(8 \times 10^{14} - 6 \times 10^{14})$$

$$= 6.6 \times 10^{-34} \times 2 \times 10^{14}\ \text{J}$$

$$= \frac{6.6 \times 10^{-34} \times 2 \times 10^{14}}{1.6 \times 10^{-19}}\text{eV}$$

$$\therefore \qquad K_{max} = \mathbf{0.83\ eV}$$

Q. 15. Two monochromatic beams A and B of equal intensity I, hit a screen. The number of photons hitting the screen by beam A is twice that by beam B. Then what inference can you make about their frequencies? **[*NCERT Exemplar*]**

Ans. Let no. of photons falling per second of beam $A = n_A$

No. of photons falling per second of beam $B = n_B$

Energy of beam $A = h\nu_A$

Energy of beam $B = h\nu_B$

According to question, $I = n_A h\nu_A = n_B h\nu_B$

$$\frac{n_A}{n_B} = \frac{\nu_B}{\nu_A} \text{ or, } \frac{2n_B}{n_B} = \frac{\nu_B}{\nu_A} \Rightarrow \nu_B = 2\nu_A$$

The frequency of beam B is twice that of A.

Q. 16. A monochromatic light source of power 5 mW emits 8×10^{15} photons per second. This light ejects photo electrons from a metal surface. The stopping potential for this set up is 2V. Calculate the work function of the metal. **[*CBSE Sample Paper 2016*]**

Ans. Given, $P = 5\times10^{-3}$ W, $N = 8 \times 10^{15}$ photons per second

Energy of each photon,

$$E = \frac{P}{N} = \frac{5\times10^{-3}}{8\times10^{15}} = 6.25\times10^{-19}\text{J} = \frac{6.25\times10^{-19}}{1.6\times10^{-19}}\text{eV}$$

$$= 3.9 \text{ eV}$$

Work function, $W_0 = E - K.E_{max} = E - eV_0$ $\quad [\because K.E_{\max} = eV_0]$

$= (3.9 - 2)$ eV$=$ **1.9 eV**

AS PER NEP CONSTRUCTED RESPONSE QUESTIONS

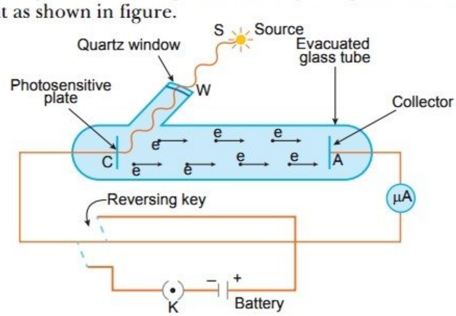
Long Answer Questions

Each of the following questions are of 5 marks.

Q. 1. Describe an experimental arrangement to study photoelectric effect. Explain the effect of (*i*) intensity of light on photoelectric current, (*ii*) potential on photoelectric current and (*iii*) frequency of incident radiation on stopping potential.

Ans. **Experimental study of Photoelectric Effect:** The apparatus consist of an evacuated glass or quartz tube which encloses a photosensitive plate C (called emitter) and a metal plate A (called collector). A transparent window W is sealed on the glass tube which can be covered with a filter for a light of particular radiation. This will allow the light of particular wavelength to pass through it.

The plate A can be given a desired positive or negative potential with respect to plate C, using the arrangement as shown in figure.



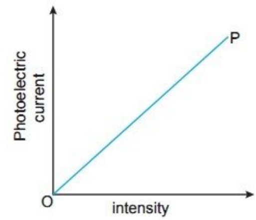
Working: When a monochromatic radiations of suitable frequency obtained from source S fall on the photosensitive plate C, the photoelectrons are emitted from C, which gets accelerated towards the plate A (collector) if it is kept at positive potential.

These electrons flow in the outer circuit resulting in the photoelectric current. Due to it, the microammeter shows a deflection. The reading of microammeter measures the photoelectric current.

This experimental arrangement can be used to study the variation of photoelectric current with the following quantities.

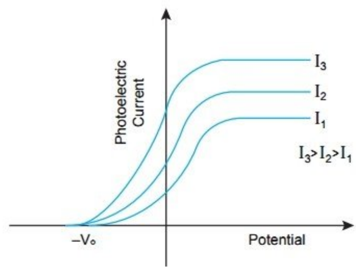
(*i*) **Effect of intensity of the incident radiation:** By varying the intensity of the incident radiations, keeping the frequency constant, it is found that the photoelectric current varies linearly with the intensity of the incident radiation.

Also, the number of photoelectrons emitted per second is directly proportional to the intensity of the incident radiations.



(*ii*) **Effect of potential of plate A w.r.t place C:** It is found that the photoelectric current increases gradually with the increase in positive potential of plate A.

At one stage for a certain positive potential of plate A, the photoelectric current becomes maximum or saturates. After this if we increase the positive potential of plate A, there will be no increase in the photoelectric current.



This maximum value of current is called saturation current: The saturation current corresponds to the state when all the photoelectrons emitted from C reach the plate A.

Now apply a negative potential on plate A w.r.t. plate C. We will note that the photoelectric current decreases, because the photoelectrons emitted from C are repelled and only energetic photoelectrons are reaching the plate A.

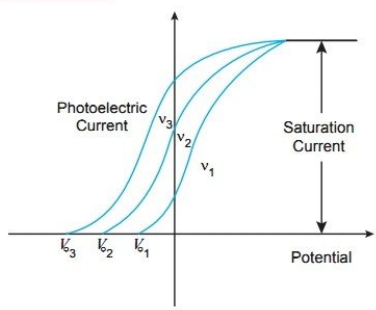
By increasing the negative potential of plate A, the photoelectric current decreases rapidly and becomes zero at a certain value of negative potential V_0 on plate A.

This maximum negative potential V_0, given to the plate A w.r.t. plate C at which the photoelectric current becomes zero is called stopping potential or cut off potential.

$$\boxed{K_{\max} = eV_0 = \frac{1}{2} m V_{\max}^2}$$

where e = charge on electron, m = mass of electrons, $V_{\max}$ = maximum velocity of emitted photoelectrons.

The value of stopping potential is independent of the intensity of the incident radiation. It means, the maximum kinetic energy of emitted photoelectrons depends on the radiation source and nature of material of plate C but is independent of the intensity of incident radiation.



(*iii*) **Effect of frequency of the incident radiation:** When we take the radiations of different frequencies but of same intensity, then the value of stopping potential is different for radiation of different frequency.

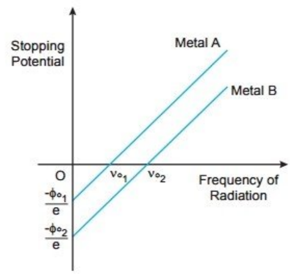
The value of stopping potential is more negative for radiation of higher incident frequency. The value of saturation current depends on the intensity of incident radiation but is independent of the frequency of the incident radiation.

(*iv*) **Effect of frequency on stopping potential:** For a given photosensitive material, the stopping potential varies linearly with the frequency of the incident radiation.

For every photosensitive material, there is a certain minimum cut off frequency ν_0 (threshold frequency) for which the stopping potential is zero.

The intercept on the potential axis $= -\frac{\phi_0}{e} = -\frac{h\nu_0}{e}$.

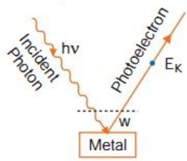
Hence, work function $\phi_0 = e \times$ magnitude of intercept on the potential axis



Q. 2. Derive Einstein's photoelectric equation $\frac{1}{2}mv^2 = h\nu - h\nu_0$.

Ans. Einstein's Explanation of Photoelectric Effect: Einstein's Photoelectric Equation

Einstein explained photoelectric effect on the basis of quantum theory. The main points are



1. Light is propagated in the form of bundles of energy. Each bundle of energy is called a **quantum** or **photon** and has energy $h\nu$ where h = Planck's constant and ν = frequency of light.
2. The photoelectric effect is due to collision of a photon of incident light and a bound electron of the metallic cathode.
3. When a photon of incident light falls on the metallic surface, it is completely absorbed. Before being absorbed it penetrates through a distance of nearly 10^{-8} m (or 100 Å). The absorbed photon transfers its whole energy to a single electron. The energy of photon goes in two parts: a part of energy is used in releasing the electron from the metal surface (*i.e.*, in overcoming work function) and the remaining part appears in the form of kinetic energy of the same electron.

If ν be the frequency of incident light, the energy of photon $= h\nu$. If W be the work function of metal and E_K the maximum kinetic energy of photoelectron, then according to Einstein's explanation.

$$h\nu = W + E_K$$

or $$E_K = h\nu - W \qquad ...(i)$$

This is called **Einstein's photoelectric equation.**

If ν_0 be the threshold frequency, then if frequency of incident light is less then ν_0 no electron will be emitted and if the frequency of incident light be ν_0 then $E_K = 0$; so from equation (*i*)

$$0 = h\nu_0 - W \quad \text{or} \quad W = h\nu_0$$

If λ_0 be the threshold wavelength, then $\nu_0 = \frac{c}{\lambda_0}$,

where c is the speed of light in vacuum

$\therefore$ Work function $\qquad W = h\nu_0 = \frac{hc}{\lambda_0}$

Substituting this value in equation (*i*), we get

$$E_K = h\nu - h\nu_0 \quad \Rightarrow \quad \frac{1}{2}mv^2 = h\nu - h\nu_0$$

This is another form of Einstein's photoelectric equation.

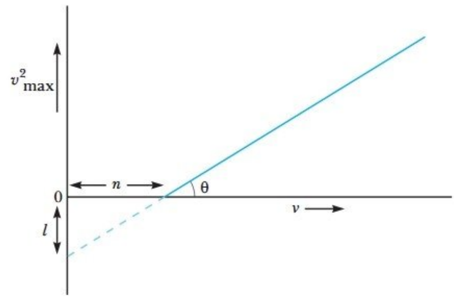
Q. 3. **(*a*) Give a brief description of the basic elementary process involved in the photoelectric emission in Einstein's picture.**

(*b*) When a photosensitive material is irradiated with the light of frequency ν, the maximum speed of electrons is given by v_{max}. A plot of v^2_{max} is found to vary with frequency ν as shown in the figure.

Use Einstein's photoelectric equation to find the expressions for

(*i*) Planck's constant and

(*ii*) work function of the given photosensitive material, in terms of the parameters *l*, *n* and mass *m* of the electron.



Ans. (*a*) Refer to Q. 2, Long Answer Questions.

(*b*) (*i*) v_1^2 and v_2^2 are the velocities of the emitted electrons for radiations of frequencies $\nu_1 > \nu$ and $\nu_2 > \nu$ respectively. So,

$$h\nu_1 = h\nu + \frac{1}{2}mv_1^2 \qquad \ldots(i)$$

and $$h\nu_2 = h\nu + \frac{1}{2}mv_2^2 \qquad \ldots(ii)$$

From equation (*i*) and (*ii*), we get

$$h(\nu_2 - \nu_1) = \frac{1}{2}m(v_2^2 - v_1^2) \quad \Rightarrow \quad h = \frac{\frac{1}{2}m(v_2^2 - v_1^2)}{(\nu_2 - \nu_1)}$$

Slope of v^2_{max} vs frequency graph is

$$\tan\theta = \frac{v_2^2 - v_1^2}{(\nu_2 - \nu_1)}$$

$$\therefore \quad h = \frac{1}{2}m \cdot \tan\theta$$

From graph $\tan\theta = \frac{l}{n}$

So, $$h = \frac{1}{2}m\left(\frac{l}{n}\right) \qquad \ldots(iii)$$

(*ii*) From graph, the work function of the material is

$$W = hn \qquad \ldots(iv)$$

From equations (*iii*) and (*iv*), we get

$$W = \frac{1}{2}m\left(\frac{l}{n}\right) \times n = \frac{1}{2}ml$$

Questions for Practice

1. **Choosen and write the correct option in the following questions.**

   (*i*) Two particles A_1 and A_2 of masses m_1, m_2 ($m_1 > m_2$) have the same de Broglie wavelength. Then *[NCERT Exemplar]*

   (*a*) their momenta are the same
   (*b*) their energies are the same
   (*c*) energy of A_1 is less than the energy of A_2
   (*d*) energy of A_1 is more than the energy of A_2

   (*ii*) The threshold frequency for a photosensitive metal is 3.3×10^{14} Hz. If light of frequency 8.2×10^{14} Hz is incident on this metal, the cut-off voltage for the photoelectron emission is nearly

   (*a*) 1 V (*b*) 2 V
   (*c*) 3 V (*d*) 5 V

   (*iii*) When the light of frequency $2\nu_0$ (where ν_0 is threshold frequency), is incident on a metal plate, the maximum velocity of electrons emitted is v_1. When the frequency of the incident radiation is increased to $5\nu_0$, the maximum velocity of electrons emitted from the same plate is v_2. The ratio of v_1 to v_2 is

   (*a*) 1 : 2 (*b*) 1 : 4
   (*c*) 4 : 1 (*d*) 2 : 1

   (*iv*) Photoelectric effect supports

   (*a*) Newton's corpuscular nature of light
   (*b*) Huygen's wave theory of light
   (*c*) Maxwell's electromagnetic theory of light
   (*d*) Einstein's quantum theory of light

   (*v*) Which one of the following metals does not exhibit emission of electrons from its surface when irradiated by visible light? *[CBSE 2023 (55/2/1)]*

   (*a*) Rubidium (*b*) Sodium (*c*) Cadmium (*d*) Caesium

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

   (a) ***Both A and R are true and R is the correct explanation of A.***
   (b) ***Both A and R are true but R is not the correct explanation of A.***
   (c) ***A is true but R is false.***
   (d) ***A is false and R is also false.***

   Assertion (*A*) **:** On increasing the frequency of light, the photocurrent remains unchanged.
   Reason (*R*) **:** Photocurrent is independent of frequency but depends only on intensity of incident light.

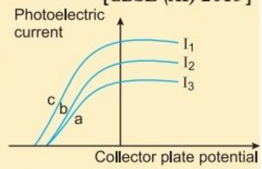
3. Plot a graph of the de Broglie wavelength associated with a proton versus its momentum.

4. In a photoelectric experiment, the potential required to stop the ejection of electrons from cathode is 4 V. What is the value of maximum kinetic energy of emitted photoelectrons? *[CBSE Sample Paper 2021]*

5. A proton and an electron have equal speeds. Find the ratio of de Broglie wavelengths associated with them. *[CBSE 2020 (55/1/1)]*

6. Write the expression for the de Broglie wavelength associated with a charged particle having charge 'q' and mass 'm', when it is accelerated by a potential V. **[*CBSE (AI) 2013*]**

7. The figure shows a plot of three curves a, b, c showing the variation of photocurrent verses collector plate potential for three different intensities I_1, I_2, and I_3 having frequencies ν_1, ν_2 and ν_3 respectively incident on a photosenitive surface.



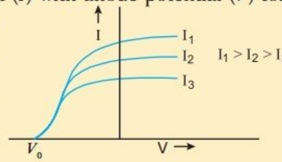
Point out the two curves for which the incident radiations have same frequency but different intensities. **[*CBSE Delhi 2009*]**

8. The stopping potential in an experiment on photoelectric effect is 1.5 V. What is the maximum kinetic energy of the photoelectrons emitted? **[*CBSE (AI) 2009*]**

9. The maximum kinetic energy of a photoelectron is 3 eV. What is its stopping potential? **[*CBSE (AI) 2009*]**

10. An electron and a proton have the same kinetic energy. Which one of the two has the larger de Broglie wavelength and why? **[*CBSE (AI) 2012*]**

11. (*a*) Draw a graph showing variation of photo-electric current (I) with anode potential (V) for different intensities of incident radiation. Name the characteristic of the incident radiation that is kept constant in this experiment.



(*b*) If the potential difference used to accelerate electrons is doubled, by what factor does the de Broglie wavelength associated with the electrons change? **[*CBSE (F) 2009*]**

12. Show on a graph the variation of the de Broglie wavelength (λ) associated with an electron, with the square root of accelerating potential (V). **[*CBSE (F) 2012*] [*HOTS*]**

13. What are matter waves? Find the ratio of de Broglie wavelengths associated with proton and alpha particles when both particles

(*a*) are accelerated through the same potential difference.

(*b*) have same velocity. **[*CBSE 2020 (55/3/2)*]**

14. Explain, how the process of emission of photoelectrons is different from the process of emission of β-particles. **[*CBSE 2020 (55/1/3)*]**

15. Light of wavelength 2500 Å falls on a metal surface of work function 3.5 eV. What is the kinetic energy (in eV) of (*i*) the fastest and (*ii*) the slowest electronic emitted from the surface?

If the same light falls on another surface of work function 5.5 eV, what will be the energy of emitted electrons?

16. In case of photo electric effect experiment, explain the following facts, giving reasons.

(*a*) The wave theory of light could not explain the existence of the threshold frequency.

(*b*) The photo electric current increases with increase of intensity of incident light. **[*CBSE 2020 (55/5/2)*]**

17. Explain how does (*i*) photoelectric current and (*ii*) kinetic energy of the photoelectrons emitted in a photocell vary if the frequency of incident radiation is doubled, but keeping the intensity same? Show the graphical variation in the above two cases. **[*CBSE Sample Paper 2022, Term-2*]**

18. Plot a graph showing variation of de Broglie wavelength (λ) associated with a charged particle of mass m, versus $1/\sqrt{V}$, where V is the potential difference through which the particle is accelerated. How does this graph give us the information regarding the magnitude of the charge of the particle?

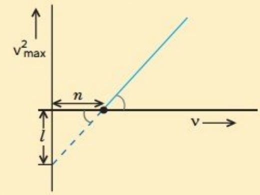
19. Light of wavelength 2000 Å falls on a metal surface of work function 4.2 eV.

(a) What is the kinetic energy (in eV) of the fastest electrons emitted from the surface?

(b) What will be the change in the energy of the emitted electrons if the intensity of light with same wavelength is doubled?

(c) If the same light falls on another surface of work function 6.5 eV, what will be the energy of emitted electrons? [*CBSE Sample Paper 2022, Term-2*]

20. When a given photosensitive material is irradiated with light of frequency ν, the maximum speed of the emitted photoelectrons equals v_{max}. The graph shown in the figure gives a plot of v^2_{max} varying with frequency ν.



Obtain an expression for

(a) Planck's constant, and

(b) The work function of the given photosensitive material in terms of the parameters '*l*', '*n*' and the mass '*m*' of the electron.

(c) How is threshold frequency determined from the plot?

21. An electron is accelerated from rest through a potential difference of 100 V. Find:

(i) the wavelength associated with

(ii) the momentum of and

(iii) the velocity required by, the electron. [*CBSE 2022 (55/3/1) Term-2*]

22. Light of same wavelength is incident on three photo-sensitive surfaces A, B and C. The following observations are recorded.

(i) From surface A, photo electrons are not emitted.

(ii) From surface B, photo electrons are just emitted.

(iii) From surface C, photo electrons with some kinetic energy are emitted. Compare the threshold frequencies of the three surfaces and justify your answer. [*CBSE 2020 (55/4/1)*]

23. How does Einstein's photoelectric equation explain the emission of electrons from a metal surface ? Explain briefly. [*CBSE 2023 (55/1/1), Term-2*]

Plot the variation of photo current with

(a) collector plate potential for different intensity of incident radiation, and

(b) intensity of incident radiation.

24. Find the (a) maximum frequency and (b) minimum wavelength of X-rays produced by 30 kV electrons. [*NCERT*]

25. An electron and a proton, each have de Broglie wavelength of 1.00 nm.

(a) Find the ratio of their momenta.

(b) Compare the kinetic energy of the proton with that of the electron.

[*NCERT*] [*CBSE (F) 2013*]

26. In an experiment of photoelectric effect, the slope of cut-off voltage versus frequency of incident light is found to be 4.12×10^{-15} Vs. Calculate the value of Planck's constant. [*NCERT*]

27. The threshold frequency for a certain metal is 3.3×10^{14} Hz. If light of frequency 8.2×10^{14} Hz is incident on the metal, predict the cut-off voltage for photoelectric emission. [*NCERT*]

28. A proton and an electron have same velocity. Which one has greater de Broglie wavelength and why? [*CBSE (AI) 2012*]

29. A proton and an alpha particle are accelerated through the same potential. Which one of the two has (*i*) greater value of de Broglie wavelength associated with it and (*ii*) less kinetic energy? Give reasons to justify your answer. **[*CBSE North 2016, Delhi 2014*]**

30. Define the terms (*i*) 'cut-off voltage' and (*ii*) 'threshold frequency' in relation to the phenomenon of photoelectric effect.

Using Einstein's photoelectric equation show how the cut-off voltage and threshold frequency for a given photosensitive material can be determined with the help of a suitable plot/graph. **[*CBSE (AI) 2012*]**

31. A proton and a deuteron are accelerated through the same accelerating potential. Which one of the two has

(*i*) greater value of de Broglie wavelength associated with it, and

(*ii*) less momentum?

Give reasons to justify your answer. **[*CBSE Delhi 2014*]**

32. A proton and an α-particle have the same de Broglie wavelength. Determine the ratio of (*i*) their accelerating potentials (*ii*) their speeds. **[*CBSE Delhi 2015; 2019 (55/4/1)*]**

33. (*a*) Define the term 'intensity of radiation' in terms of photon picture of light.

(*b*) Two monochromatic beams, one red and the other blue, have the same intensity. In which case (*i*) the number of photons per unit area per second is larger, (*ii*) the maximum kinetic energy of the photoelectrons is more? Justify your answer. **[*CBSE Patna 2015*]**

34. Ultraviolet light of wavelength 2270 Å from 100 W mercury source irradiates a photo cell made of a given metal. If the stopping potential is –1.3 V, estimate the work function of the metal. How would the photocell respond to a high intensity ($\sim 10^5$ Wm^{-2}) red light of wavelength 6300 Å produced by a laser? **[*CBSE Bhubaneshwar 2015*]**

Answers

1. (*i*) (*a*), (*c*)	(*ii*) (*b*)	(*iii*) (*a*)	(*iv*) (*d*)	(*v*) (*c*)
2. (*a*)	**4.** 4 eV	**5.** $5.45 \times 10^{-4} : 1$		**8.** 2.4×10^{-19} J
9. 3V	**13.** (*a*) $2\sqrt{2}:1$	(*b*) 4 : 1		**15.** (*i*) 1.47 eV (*ii*) 0
19. (*a*) 2.0 eV		**24.** (*a*) 7.24×10^{18} Hz		(*b*) 0.041 mm
25. (*a*) 1 : 1	(*b*) 5.4×10^{-4}			**26.** 6.59×10^{-34} Js
32. (*i*) 8 : 1	(*ii*) 4 : 1	**34.** 4.2 eV		

12 Atoms

POINTS TO REMEMBER

1. Geiger-Marsden's α-particle Scattering Experiment

On the suggestion of Rutherford, in 1911, his two associates, H. Geiger and E. Marsden, performed an experiment by bombarding α-particles (Helium nuclei $Z = 2, A = 4$) on a gold foil.

Observations:

(i) Most of the α-particles pass through the gold foil undeflected.

(ii) A very small number of α-particles (1 in 8000) suffered large angle deflection; some of them retraced their path or suffered 180° deflection.

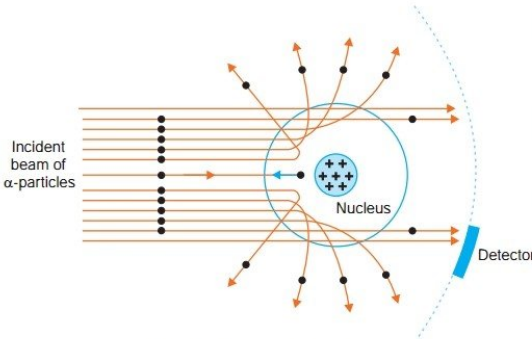
Conclusion:

(i) Atom is hollow.

(ii) Entire positive charge and nearly whole mass of atom is concentrated in a small centre called nucleus of atom.

(iii) Coulomb's law holds good for atomic distances.

(iv) Negatively charged electrons are outside the nucleus.



Rutherford Scattering experiment

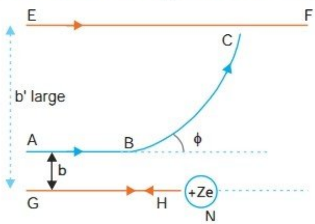
Impact Parameter: The perpendicular distance of initial velocity vector of α-particle from the nucleus, when the particle is far away from the nucleus, is called the impact parameter. It is denoted by b. For head on approach of α-particle, $b = 0$.

Angle of Scattering (ϕ) : The angle by which α-particle is deviated from its original direction is called angle of scattering.

$$b = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{E_K}\cot\frac{\phi}{2}$$

where E_k is the initial kinetic energy for head on approach of alpha particle.

Impact parameter, $b = 0$.



2. Distance of Closest Approach

The smallest distance of approach of α-particle near heavy nucleus is a measure of the size of nucleus.

Distance of nearest approach ≈ size of nucleus $= \frac{1}{4\pi\varepsilon_0}\frac{2Ze^2}{E_K}$

where E_K is kinetic energy of incident α-particle, Z = atomic number, e = electronic charge.

3. Rutherford's Atom Model

Atom consists of a central heavy nucleus containing positive charge and negatively charged electrons circulating around the nucleus in circular orbits.

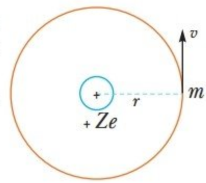
Rutherford model could explain the neutrality of an atom, thermionic emission and photoelectric effect; but it could not explain the stability of an atom and the observed line spectrum of an atom (atomic spectrum).

4. Bohr's Model

Bohr modified Rutherford atom model to explain the line spectrum of hydrogen.

Postulates of Bohr's Theory

(*i*) **Stationary Circular Orbits:** An atom consists of a central positively charged nucleus and negatively charged electrons revolve around the nucleus in certain orbits called **stationary orbits.**



The electrostatic coulomb force between electrons and the nucleus provides the necessary centripetal force.

i.e., $\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(e)}{r^2}$

where Z is the atomic number, m is the mass of electrons, r = radius of orbit.

(*ii*) **Quantum Condition:** The stationary orbits are those in which angular momentum of electron is an integral multiple of $\frac{h}{2\pi}$, *i.e.*,

$$mvr = n\frac{h}{2\pi}, \quad n = 1, 2, 3,...$$

Integer n is called the principal quantum number. This equation is called Bohr's quantum condition.

(*iii*) **Transitions:** The electron does not radiate energy when in a stationary orbit. The quantum of energy (or photon) is emitted or absorbed when an electron jumps from one stationary orbit to the other. The frequency of emitted or absorbed photon is given by

$$h\nu = |E_i - E_f|$$

This is called Bohr's frequency condition.

Radius of Orbit and Energy of Electron in Orbit

Condition of motion of electron in circular orbit is

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(e)}{r^2} \qquad ...(i)$$

Bohr's quantum condition is

$$mvr = n\frac{h}{2\pi} \qquad ...(ii)$$

$$\Rightarrow \qquad v = \frac{nh}{2\pi mr}$$

Substituting this value of v in (*i*), we get

$$\frac{m}{r}\left(\frac{nh}{2\pi mr}\right)^2 = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r^2}$$

This gives $r = \dfrac{\varepsilon_0 h^2 n^2}{\pi m Z e^2}$

Denoting radius of nth orbit by r_n, we have

$$r_n = \frac{\varepsilon_0 h^2 n^2}{\pi m Z e^2} \qquad \dots(iii)$$

For hydrogen atom $Z = 1$,

$$\therefore \qquad (r_n)_H = \frac{\varepsilon_0 h^2 n^2}{\pi m e^2}$$

The radius of first orbit of hydrogen atom is called Bohr's radius. It is denoted by a_0

$$\Rightarrow \qquad a_0 = \frac{\varepsilon_0 h^2}{\pi m e^2} = 0.529 \times 10^{-10}\,\text{m} = 0.529\ \text{Å}$$

Energy of Orbiting Electron

From equation (*i*), $\qquad mv^2 = \dfrac{1}{4\pi\varepsilon_0}\dfrac{Ze^2}{r}$

Kinetic energy, $\qquad K = \dfrac{1}{2}mv^2 = \dfrac{1}{4\pi\varepsilon_0}\dfrac{Ze^2}{2r}$

Potential energy, $\qquad U = \dfrac{1}{4\pi\varepsilon_0}\dfrac{(Ze)(-e)}{r} = -\dfrac{1}{4\pi\varepsilon_0}\dfrac{Ze^2}{r}$

Total energy $\qquad E = K + U = \dfrac{1}{4\pi\varepsilon_0}\dfrac{Ze^2}{2r} - \dfrac{1}{4\pi\varepsilon_0}\dfrac{Ze^2}{r}$

$$\Rightarrow \qquad E = -\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{2r}$$

For nth orbit, writing E_n for E, we have

$$E_n = -\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{2r_n} \qquad \dots(iv)$$

Substituting the value of r_n from (*iii*) in (*iv*), we get

$$E_n = -\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{2\left(\dfrac{\varepsilon_0 h^2 n^2}{\pi m Z e^2}\right)} = -\frac{mZ^2e^4}{8\varepsilon_0^2 h^2 n^2} \qquad \dots(v)$$

For convenience introducing Rydberg constant, $R = \dfrac{me^4}{8\varepsilon_0^2 ch^3}$ $\qquad \dots(vi)$

The value of Rydberg constant is $1.097 \times 10^7\ \text{m}^{-1}$.

We have

$$E_n = -\frac{Z^2 Rhc}{n^2} \qquad \dots(vii)$$

For hydrogen atom $Z = 1$,

Energy of orbiting electron in H-atom

$$E_n = -\frac{Rhc}{n^2}$$

$$\Rightarrow \qquad E_n = -\frac{13.6}{n^2}\ \text{eV}$$

Equations (*iii*) and (*vii*) indicate that radii and energies of hydrogen like atoms (*i.e.*, atoms containing one electron only) are quantised.

5. Energy Levels of Hydrogen Atom

The energy of electron in hydrogen atom ($Z = 1$) is given (or series of hydrogen spectrum) by

$$E_n = -\frac{Rhc}{n^2} = -\frac{13.6}{n^2}\text{eV};$$

when $n = 1$, $\quad E_1 = -13.6$ eV

when $n = 2$, $\quad E_2 = -\frac{13.6}{4}\text{eV} = -3.4\text{ eV}$

when $n = 3$, $\quad E_3 = -\frac{13.6}{9}\text{eV} = -1.51\text{ eV}$

when $n = 4$, $\quad E_4 = -\frac{13.6}{16}\text{eV} = -0.85\text{ eV}$

when $n = 5$, $\quad E_5 = -\frac{13.6}{25}\text{eV} = -0.54\text{ eV}$

when $n = 6$, $\quad E_6 = -\frac{13.6}{36}\text{eV} = -0.38\text{ eV}$

when $n = 7$, $\quad E_7 = -\frac{13.6}{49}\text{eV} = -0.28\text{ eV}$

....

....

when $n = \infty$, $\quad E_\infty = -\frac{13.6}{(\infty)^2}\text{eV} = 0\text{ eV}$

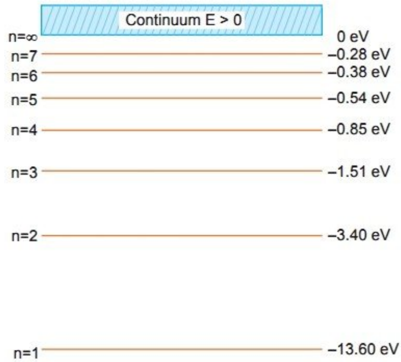


Fig. (a) Energy Level Diagram

If these energies are expressed by vertical lines on proper scale, the diagram obtained is called the energy level diagram. The energy level diagram of hydrogen atom is shown in fig. (*a*). Clearly the separation between lines goes on decreasing rapidly with increase of n (*i.e.*, order of orbit). The series of lines of H-spectrum are shown in fig. (*b*).

If the total energy of electron is above zero, the electron is free and can have any energy. Thus there is a continuum of energy states above $E = 0$ eV.

6. Hydrogen Spectrum

Hydrogen emission spectrum consists of 5 series.

(*i*) **Lyman series:** This lies in ultraviolet region.

(*ii*) **Balmer series:** This lies in the visible region.

(*iii*) **Paschen series:** This lies in near infrared region.

(*iv*) **Brackett series:** This lies in mid infrared region.

(*v*) **Pfund series:** This lies in far infrared region.

Hydrogen absorption spectrum consists of only Lyman series.

Explanation of Hydrogen Spectrum: n_i and n_f are the quantum numbers of initial and final states and E_i and E_f are energies of electron in H-atom ($Z = 1$) in initial and final states then we have

$$E_i = -\frac{Rhc}{n_i^2} \text{ and } E_f = -\frac{Rhc}{n_f^2}$$

Energy of absorbed photon

$$\Delta E = E_f - E_i = Rhc\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

If ν is the frequency of emitted radiation, we have from Bohr's fourth postulate

$$\nu = \frac{E_i - E_f}{h} = -\frac{Rc}{n_i^2} - \left(-\frac{Rc}{n_f^2}\right) = Rc\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

The wave number (*i.e.*, reciprocal of wavelength) of the emitted radiation is given by

$$\bar{\nu} = \frac{1}{\lambda} = \frac{\nu}{c} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

The relation explains successfully the origin of various lines in the spectrum of hydrogen atom. The series of lines are obtained due to the transition of electron from various other orbits to a fixed inner orbit.

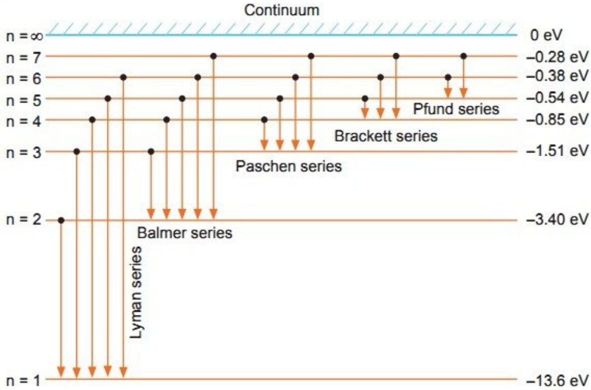


Fig. (b) Series of H-spectrum

(*i*) **Lyman series:** This series is produced when electron jumps from higher orbits to the first stationary orbit (*i.e.*, $n_f = 1$). Thus for this series

$$\bar{\nu} = \frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{n_i^2}\right) \qquad \text{where } n_i = 2, 3, 4, 5, \ldots$$

For longest wavelength of Lyman series $n_i = 2$

$$\therefore \qquad \frac{1}{\lambda_{\max}} = R\left(\frac{1}{1^2} - \frac{1}{2^2}\right) = \frac{3R}{4}$$

$$\therefore \qquad \lambda_{\max} = \frac{4}{3R} = \frac{4}{3 \times 1.097 \times 10^7}\,\text{m}$$

$$= 1.215 \times 10^{-7}\ \text{m} = 1215\ \text{Å}$$

For shortest wavelength of Lyman series $n_i = \infty$

$$\therefore \qquad \frac{1}{\lambda_{\min}} = R\left(\frac{1}{1^2} - \frac{1}{\infty}\right) = R$$

$$\lambda_{\min} = \frac{1}{R} = \frac{1}{1.097 \times 10^7}\,\text{m} = 0.9116 \times 10^{-7}\,\text{m} = 911.6\ \text{Å}$$

This is called series limit of Lyman series $\lambda_{\text{limit}} = 911.6$ Å

Obviously the lines of Lyman series are found in ultraviolet region.

(*ii*) **Balmer series:** The series is produced when an electron jumps from higher orbits to the second stationary orbit ($n_f = 2$). Thus for this series,

$$\bar{\nu} = \frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n_i^2}\right) \qquad \text{where } n_i = 3, 4, 5, 6, \ldots$$

For Longest wavelength of Balmer series ($n_i = 3$)

$$\frac{1}{\lambda_{\max}} = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right) = \frac{5R}{36}$$

$$\lambda_{max} = \frac{36}{5R} = \frac{36}{5 \times 1.097 \times 10^{7}} \text{m} = 6.563 \times 10^{-7} \text{m} = 6563 \text{ Å}$$

For Shortest wavelength (or series limit) of Balmer series $n_i \rightarrow \infty$

$$\therefore \qquad \frac{1}{\lambda_{min}} = R\left(\frac{1}{2^2} - \frac{1}{\infty}\right) = \frac{R}{4}$$

$$\lambda_{min} = \frac{4}{R} = \frac{4}{1.097 \times 10^{-7}} \text{m} = 3.646 \times 10^{-7} \text{ m} = 3646 \text{ Å}$$

Obviously the lines of Balmer series are found in the visible region and first, second, third … lines are called H_α, H_β, H_γ..., lines respectively.

(iii) **Paschen series:** This series is produced when an electron jumps from higher orbits to the third stationary orbit ($n_f = 3$).

$$\bar{\nu} = \frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{n_i^2}\right) \quad \text{where } n_i = 4, 5, 6, 7, ...$$

For Longest wavelength of Paschen series ($n_i = 4$)

$$\therefore \qquad \frac{1}{\lambda_{max}} = R\left(\frac{1}{3^2} - \frac{1}{4^2}\right) = \frac{7R}{144}$$

$$\therefore \qquad \lambda_{max} = \frac{144}{7R} = \frac{144}{7 \times 1.097 \times 10^{7}} \text{m} = 18.752 \times 10^{-7} \text{ m} = 18752 \text{ Å}$$

For Series limit of Paschen series ($n_i = \infty$)

$$\frac{1}{\lambda_{min}} = R\left(\frac{1}{3^2} - \frac{1}{\infty}\right) = \frac{R}{9}$$

$$\lambda_{min} = \frac{9}{R} = \frac{9}{1.097 \times 10^{7}} = 8.204 \times 10^{-7} \text{ m} = 8204 \text{ Å}$$

Obviously lines of Paschen series are found in infrared region.

(iv) **Brackett series:** This series is produced when an electron jumps from higher orbits to the fourth stationary orbit ($n_f = 4$)

$$\bar{\nu} = \frac{1}{\lambda} = R\left(\frac{1}{4^2} - \frac{1}{n_i^2}\right) \quad \text{where } n_i = 5, 6, 7, 8, ...$$

(v) **Pfund series:** This series is produced when an electron jumps from higher orbits to the fifth stationary orbit ($n_f = 5$)

$$\bar{\nu} = \frac{1}{\lambda} = R\left(\frac{1}{5^2} - \frac{1}{n_i^2}\right) \quad \text{where } n_i = 6, 7, 8, ...$$

The last three series are found in infrared region.

The series spectrum of hydrogen atom is represented in figure.

Multiple Choice Questions

Choose and write the correct option(s) in the following questions.

1. The potential energy of an electron in the second excited state in hydrogen atom is *[CBSE 2023 (55/4/1)]*

(*a*) –3.4 eV (*b*) –3.02 eV

(*c*) –1.51 eV (*d*) –6.8 eV

2. **To explain his theory, Bohr used**
   (*a*) conservation of linear momentum
   (*b*) quantisation of angular momentum
   (*c*) conservation of quantum
   (*d*) none of these

3. **Taking the Bohr radius as $a_0 = 53$ pm, the radius of Li^{++} ion in its ground state, on the basis of Bohr's model, will be about** **[*NCERT Exemplar*]**
   (*a*) 53 pm (*b*) 27 pm (*c*) 18 pm (*d*) 13 pm

4. **The ratio of energies of the hydrogen atom in its first to second excited state is**
   (*a*) 1 : 4 (*b*) 4 : 1 (*c*) $-4 : -9$ (*d*) $-\frac{1}{4} : -\frac{1}{9}$

5. **The binding energy of a H-atom, considering an electron moving around a fixed nuclei (proton), is $B = -\frac{me^4}{8n^2\varepsilon_0^2h^2}$ (m = electron mass).**

   If one decides to work in a frame of reference where the electron is at rest, the proton would be moving arround it. By similar arguments, the binding energy would be

   $B = -\frac{me^4}{8n^2\varepsilon_0^2h^2}$ **(M = proton mass)** **[*NCERT Exemplar*]**

   This last expression is not correct because
   (*a*) n would not be integral
   (*b*) Bohr-quantisation applies only to electron
   (*c*) the frame in which the electron is at rest is not inertial
   (*d*) the motion of the proton would not be in circular orbits, even approximately

6. **The simple Bohr model cannot be directly applied to calculate the energy levels of an atom with many electrons. This is because** **[*NCERT Exemplar*]**
   (*a*) of the electrons not being subject to a central force
   (*b*) of the electrons colliding with each other
   (*c*) of screening effects
   (*d*) the force between the nucleus and an electron will no longer be given by Coulomb's law

7. **The ratio of the speed of the electrons in the ground state of hydrogen to the speed of light in vacuum is**
   (*a*) 1/2 (*b*) 2/237 (*c*) 1/137 (*d*) 1/237

8. **For the ground state, the electron in the H-atom has an angular momentum = $\hbar$, according to the simple Bohr model. Angular momentum is a vector and hence there will be infinitely many orbits with the vector pointing in all possible directions. In actuality, this is not true,** **[*NCERT Exemplar*]**
   (*a*) because Bohr model gives incorrect values of angular momentum.
   (*b*) because only one of these would have a minimum energy.
   (*c*) angular momentum must be in the direction of spin of electron.
   (*d*) because electrons go around only in horizontal orbits.

9. **O_2 molecule consists of two oxygen atoms. In the molecule, nuclear force between the nuclei of the two atoms** **[*NCERT Exemplar*]**
   (*a*) is not important because nuclear forces are short-ranged.
   (*b*) is as important as electrostatic force for binding the two atoms.
   (*c*) cancels the repulsive electrostatic force between the nuclei.
   (*d*) is not important because oxygen nucleus have equal number of neutrons and protons.

10. In the following transitions of the hydrogen atom, the one which gives an absorption line of highest frequency is

(*a*) $n = 1$ to $n = 2$ (*b*) $n = 3$ to $n = 8$

(*c*) $n = 2$ to $n = 1$ (*d*) $n = 8$ to $n = 3$

11. Hydrogen atom initially in the ground state, absorbs a photon which excites it to $n = 5$ level. The wavelength of the photon is **[*CBSE 2023 (55/1/1)*]**

(*a*) 975 nm (*b*) 740 nm (*c*) 523 nm (*d*) 95 nm

12. Two H atoms in the ground state collide inelastically. The maximum amount by which their combined kinetic energy is reduced is **[*NCERT Exemplar*]**

(*a*) 10.20 eV (*b*) 20.40 eV (*c*) 13.6 eV (*d*) 27.2 eV

13. When an electron in an atom goes from a lower to a higher orbit, its

(*a*) kinetic energy (*KE*) increases, potential energy (*PE*) decreases

(*b*) *KE* increases, *PE* increases

(*c*) *KE* decreases, *PE* increases

(*d*) *KE* decreases, *PE* decreases

14. A hydrogen atom makes a transition from $n = 5$ to $n = 1$ orbit. The wavelength of photon emitted is λ. The wavelength of photon emitted when it makes a transition from $n = 5$ to $n = 2$ orbit is **[*CBSE 2023 (55/2/1)*]**

(*a*) $\frac{8}{7}\lambda$ (*b*) $\frac{16}{7}\lambda$ (*c*) $\frac{24}{7}\lambda$ (*d*) $\frac{32}{7}\lambda$

15. If an electron in a hydrogen atom jumps from the 3rd orbit to the 2nd orbit, it emits a photon of wavelength λ. When it jumps from the 4th orbit to the 3rd orbit, the corresponding wavelength of the photon will be

(*a*) $\frac{16}{25}\lambda$ (*b*) $\frac{9}{16}\lambda$ (*c*) $\frac{20}{7}\lambda$ (*d*) $\frac{20}{13}\lambda$

16. Hydrogen H, deuterium D, singly-ionised helium He^+ and doubly-ionised lithium Li^{++} all have one electron around the nucleus. Consider $n = 2$ to $n = 1$ transition. The wavelengths of the emitted radiations are $\lambda_1, \lambda_2, \lambda_3$, and λ_4 respectively. Then approximately

(*a*) $\lambda_1 = 2\lambda_2 = 2\sqrt{2}\lambda_3 = 3\sqrt{2}\lambda_4$ (*b*) $\lambda_1 = \lambda_2 = 2\lambda_3 = 3\lambda_4$

(*c*) $\lambda_1 = \lambda_2 = 4\lambda_3 = 9\lambda_4$ (*d*) $4\lambda_1 = 2\lambda_2 = 2\lambda_3 = \lambda_4$

17. The Bohr model for the spectra of a H-atom **[*NCERT Exemplar*]**

(*a*) will not be applicable to hydrogen in the molecular from.

(*b*) will not be applicable as it is for a He-atom.

(*c*) is valid only at room temperature.

(*d*) predicts continuous as well as discrete spectral lines.

18. Let $E_n = \frac{1}{8\varepsilon_0^2}\frac{me^4}{n^2h^2}$ be the energy of the *n*th level of H-atom. If all the H-atoms are in the ground state and radiation of frequency $(E_2 - E_1)/h$ falls on it, **[*NCERT Exemplar*]**

(*a*) it will not be absorbed at all.

(*b*) some of atoms will move to the first excited state.

(*c*) all atoms will be excited to the $n = 2$ state.

(*d*) no atoms will make a transition to the $n = 3$ state.

19. If ν_1 is the frequency of the series limit of Lyman series, ν_2 is the frequency of the first line of Lyman series and ν_3 is the frequency of the series limit of the Balmer series. Then **[*HOTS*]**

(*a*) $\nu_1 - \nu_2 = \nu_3$ (*b*) $\nu_1 + \nu_2 = \nu_3$

(*c*) $\frac{1}{\nu_2} = \frac{1}{\nu_1} + \frac{1}{\nu_3}$ (*d*) $\frac{1}{\nu_2} = \frac{1}{\nu_1} - \frac{1}{\nu_3}$

20. Which of the following statements is not correct according to Rutherford model? *[CBSE 2020 (55/1/1)]*

(*a*) Most of the space inside an atom is empty.

(*b*) The electrons revolve around the nucleus under the influence of coulomb force acting on them.

(*c*) Most part of the mass of the atom and its positive charge are concentrated at its centre.

(*d*) The stability of atom was established by the model.

21. In Bohr's model of hydrogen atom, the total energy of the electron in n^{th} discrete orbit is proportional to *[CBSE 2020 (55/3/1), 2023 (55/1/1)]*

(*a*) n (*b*) $\frac{1}{n}$

(*c*) n^2 (*d*) $\frac{1}{n^2}$

22. Paschen series of atomic spectrum of hydrogen gas lies in *[CBSE 2020 (55/4/1)]*

(*a*) Infrared region

(*b*) Ultraviolet region

(*c*) Visible region

(*d*) Partly in ultraviolet and partly in visible region

23. Which state of triply ionised beryllium (Be^{+++}) has the same orbital radius as that of the ground state of hydrogen?

(*a*) $n = 1$ (*b*) $n = 2$

(*c*) $n = 3$ (*d*) $n = 4$

Answers

1. (*b*)	**2.** (*b*)	**3.** (*c*)	**4.** (*d*)	**5.** (*c*)	**6.** (*a*)	**7.** (*c*)
8. (*a*)	**9.** (*a*)	**10.** (*a*)	**11.** (*d*)	**12.** (*a*)	**13.** (*c*)	**14.** (*d*)
15. (*c*)	**16.** (*c*)	**17.** (*a*), (*b*)	**18.** (*b*), (*d*)	**19.** (*a*)	**20.** (*d*)	**21.** (*d*)
22. (*a*)	**23.** (*b*)					

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(a) ***Both A and R are true and R is the correct explanation of A.***

(b) ***Both A and R are true but R is not the correct explanation of A.***

(c) ***A is true but R is false.***

(d) ***A is false and R is also false.***

1. Assertion(*A*) : Paschen series lies in the infrared region.

Reason (*R*) : Paschen series corresponds to the wavelength given by $\frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right)$, where $n = 4, 5, 6, ..., \infty$.

2. Assertion(*A*) : The electrons have orbital angular momentum.

Reason (*R*) : Electrons have well-defined quantum states.

3. Assertion(*A*) : Large angle of scattering of α-particles led to the discovery of atomic nucleus.

Reason (*R*) : Entire positive charge of atom is concentrated in the central core.

4. **Assertion(*A*)** : Bohr's postulate states that the electrons in stationary orbits around the nucleus do not radiate.

Reason (*R*) : According to classical physics, all moving electrons radiate.

5. **Assertion(*A*)** : In the Bohr model of the hydrogen, atom, v and E represent the speed of the electron and the total energy of the electron respectively. Then v/E is proportional to the quantum number n of the electron.

Reason (*R*) : $v \propto n$ and $E \propto n^{-2}$

6. **Assertion(*A*)** : When a hydrogen atom emits a photon in transiting for $n = 4$ to $n = 1$, its recoil speed is about 4 m/s.

Reason (*R*) : $v = \dfrac{p}{m} = \dfrac{E}{mc} = \dfrac{13.6 \times \left(1 - \dfrac{1}{16}\right) \text{eV}}{1.67 \times 10^{-27} \text{kg} \times 3 \times 10^{8} \text{ m/s}}$

7. **Assertion(*A*)** : Electrons in the atom are held due to coulomb forces.

Reason (*R*) : The atom is stable only because the centripetal force due to Coulomb's law is balanced by the centrifugal force.

8. **Assertion(*A*)** : Bohr's postulate states that the stationary orbits are those for which the angular momentum is some integral multiple of $\dfrac{h}{2\pi}$.

Reason (*R*) : Linear momentum of the electron in the atom is quantised.

9. **Assertion(*A*)** : The total energy of an electron revolving in any stationary orbit is negative.

Reason (*R*) : Energy can have positive or negative values.

10. **Assertion(*A*)** : Hydrogen atom consists of only one electron but its emission spectrum has many lines.

Reason (*R*) : Only Lyman series is found in the absorption spectrum of hydrogen atom whereas in the emission spectrum, all the series are found.

Answers

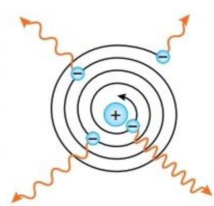
1. (*a*) **2.** (*b*) **3.** (*b*) **4.** (*a*) **5.** (*c*) **6.** (*c*) **7.** (*a*)
8. (*c*) **9.** (*c*) **10.** (*b*)

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Case-based/Passage-based Questions

Read the passages given below and answer the questions that follow:

The Bohr Atom: Rutherford's model of the atom, although strongly supported by evidence for the nucleus, is inconsistent with classical physics. An electron moving in a circular orbit round a nucleus is accelerating and according to electromagnetic theory it should emit radiation continuously and so lose energy. If this happened the radius of the orbit would decrease and the electron would spiral into the nucleus. Evidently either this model of the atom or the classical theory of radiation requires modification.



In 1913, in an effort to overcome this paradox, Bohr, drawing inspiration from the success of the quantum theory in solving other problems involving radiation and atoms, made two revolutionary suggestions.

(*a*) Electrons can revolve round the nucleus only in certain 'allowed orbits' and while they are in these orbits they do not emit radiation. An electron in an orbit has a definite amount of energy. It possesses kinetic energy because of its motion and potential energy on account of the attraction of the nucleus. Each allowed orbit is therefore associated with a certain quantity of energy, called the 'energy of the orbit', which equals the total energy of an electron in it.

(*b*) An electron can 'jump' from one orbit of energy E_2 to another of lower energy E_1 and the energy difference is emitted as one quantum of radiation of frequency f given by Planck's equation $E_2 - E_1 = hf$.

(*i*) According to Bohr's model of hydrogen atom, an electron can revolve round a proton indefinitely, if its path is

(*a*) a perfect circle of any radius
(*b*) a circle of constantly decreasing radius
(*c*) a circle of an allowed radius
(*d*) an ellipse

(*ii*) In Bohr model of hydrogen atom, which of the following is quantised?

(*a*) Linear velocity of electron
(*b*) Angular velocity of electron
(*c*) Linear momentum of electron
(*d*) Angular momentum of electron

(*iii*) For an electron in the second orbit of hydrogen, what is the moment of momentum as per the Bohr's model?

(*a*) $2\pi h$
(*b*) πh
(*c*) h/π
(*d*) $2h/\pi$

OR

An electron orbiting in H atom has energy level –3.4 eV. Its angular momentum will be

(*a*) 2.1×10^{-34} Js
(*b*) 2.1×10^{-20} Js
(*c*) 4×10^{-20} Js
(*d*) 4×10^{-34} Js

(*iv*) The Bohr's model is applicable to which kind of atoms?

(*a*) Having one electron only
(*b*) Having two electrons
(*c*) Having eight electrons
(*d*) Having more than eight electrons

Explanations

(*i*) (*c*) In Bohr's model of hydrogen atom, an electron can revolve around nucleus only in a circle of allowed radius.

(*ii*) (*d*) In Bohr model of hydrogen atom, angular momentum of electron is quantised.

(*iii*) (*c*) In second orbit of hydrogen, $n = 2$

$$L = 2\left(\frac{h}{2\pi}\right) = \frac{h}{\pi}$$

OR

(*a*) The electron revolving in second orbit ($n = 2$) has energy equal to –3.4 eV. Therefore, its angular momentum is

$$L = 2\left(\frac{h}{2\pi}\right) = \frac{h}{\pi} = \frac{6.6\times10^{-34}\,\text{Js}}{22/7} = 2.1 \times 10^{-34}\text{ Js}$$

(*iv*) (*a*) Bohr's model is applicable to hydrogen - like species *i.e.*, atoms having one electron only. Such species are also called hydrogen like species.

CONCEPTUAL QUESTIONS

Q. 1. Write the expression for Bohr's radius in hydrogen atom. [*CBSE Delhi 2010*]

Ans. Bohr's radius, $r_1 = \dfrac{\varepsilon_0 h^2}{\pi m e^2} = \mathbf{0.529 \times 10^{-10}\,m}$

Q. 2. In the Rutherford scattering experiment the distance of closest approach for an α-particle is d_0. If α-particle is replaced by a proton, how much kinetic energy in comparison to α-particle will it require to have the same distance of closest approach d_0? [*CBSE (F) 2009*]

Ans. $E_k = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(2e)}{d_0}$ (for α-particle, $q = 2e$)

$E'_k = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(e)}{d_0}$ (for proton, $q = e$)

$\frac{E'_k}{E_k} = \frac{1}{2} \quad \Rightarrow \quad \boldsymbol{E'_k = \frac{E_k}{2}}$

That is KE of proton must be half on comparison with KE of α-particle.

Q. 3. What is the ratio of radii of the orbits corresponding to first excited state and ground state in a hydrogen atom? [*CBSE Delhi 2010*]

Ans. $r_n = \frac{\varepsilon_0 h^2 n^2}{\pi m e^2} \propto n^2$

For 1^{st} excited state, $n = 2$

For ground state, $n = 1$

$\therefore \quad \boldsymbol{\frac{r_2}{r_1} = \frac{4}{1}}$

Q. 4. Find the ratio of energies of photons produced due to transition of an electron of hydrogen atom from its:

(*i*) second permitted energy level to the first level, and

(*ii*) the highest permitted energy level to the first permitted level. [*CBSE (AI) 2010*]

Ans. $E_I = Rhc\left(\frac{1}{1^2} - \frac{1}{2^2}\right) = \frac{3}{4}Rhc$

$E_{II} = Rhc\left(\frac{1}{1^2} - \frac{1}{\infty^2}\right) = Rhc$

Ratio, $\frac{E_I}{E_{II}} = \boldsymbol{\frac{3}{4}}$

Q. 5. State Bohr's quantisation condition for defining stationary orbits. [*CBSE (F) 2010*]

Ans. Quantum Condition: The stationary orbits are those in which angular momentum of electron is an integral multiple of $\frac{h}{2\pi}$ *i.e.*,

$$mvr = n\frac{h}{2\pi} \qquad n = 1, 2, 3, ...$$

Integer n is called the **principal quantum number**. This equation is called Bohr's quantum condition.

Q. 6. The radius of innermost electron orbit of a hydrogen atom is 5.1×10^{-11} m. What is the radius of orbit in the second excited state? [*CBSE Delhi 2010*]

Ans. In ground state, $n = 1$

In second excited state, $n = 3$

As $\quad r_n \propto n^2$

$\therefore \quad \frac{r_3}{r_1} = \left(\frac{3}{1}\right)^2 = 9$

$r_3 = 9r_1 = 9 \times 5.1 \times 10^{-11}$ m $= \mathbf{4.59 \times 10^{-10}}$ **m**

Q. 7. What is the value of angular momentum of electron in the second orbit of Bohr's model of hydrogen atom? *[CBSE Sample Paper 2021]*

Ans. According to Bohr,

The angular momentum of an orbiting electron $= \dfrac{nh}{2\pi}$

Here, $n = 2$

Angular momentum $= \dfrac{2 \times h}{2\pi} = \dfrac{\boldsymbol{h}}{\boldsymbol{\pi}}$

Q. 8. When an electron falls from a higher energy to a lower energy level, the difference in the energies appears in the form of electromagnetic radiation. Why cannot it be emitted as other forms of energy? *[NCERT Exemplar] [HOTS]*

Ans. This is because electrons interact only electromagnetically.

Q. 9. Would the Bohr formula for the H-atom remain unchanged if proton had a charge $(+4/3)e$ and electron had a charge $(-3/4)e$, where $e = 1.6 \times 10^{-19}$ C? Give reasons for your answer. *[NCERT Exemplar] [HOTS]*

Ans. Yes, since the Bohr formula involves only the product of the charges.

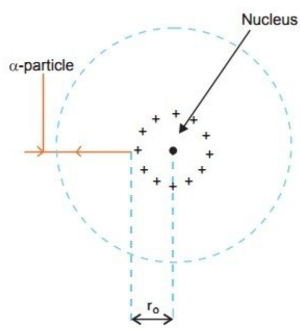
Q. 10. Consider two different hydrogen atoms. The electron in each atom is in an excited state. Is it possible for the electrons to have different energies but the same orbital angular momentum according to the Bohr model? *[NCERT Exemplar] [HOTS]*

Ans. No, because according to Bohr model, $E_n = -\dfrac{13.6}{n^2}$, and electrons having different energies belong to different levels having different values of n. So, their angular momenta will be different, as $mvr = \dfrac{nh}{2\pi}$.

Very Short Answer Questions

Each of the following questions are of 2 marks.

Q. 1. Define the distance of closest approach. An α-particle of kinetic energy 'K' is bombarded on a thin gold foil. The distance of the closest approach is 'r'. What will be the distance of closest approach for an α-particle of double the kinetic energy? *[CBSE Delhi 2017, 2022 (55/1/1), Term-2]*



Ans. Distance of closest approach is the distance of charged particle from the centre of the nucleus, at which the entire initial kinetic energy of the charged particles gets converted into the electric potential energy of the system.

Distance of closest approach (r_o) is given by

$$r_o = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2Ze^2}{K}$$

If 'K' is doubled, r_o becomes $\dfrac{r_o}{2}$.

Q. 2. Consider two different hydrogen atoms. The electron in each atom is in an excited state. Is it possible for the electrons to have different energies but same orbital angular momentum according to the Bohr model? Justify your answer. *[CBSE Sample Paper 2022, Term-2]*

Ans. No

Because according to Bohr's model,

$E_n = -\frac{13.6}{n^2}$ and electrons having different energies belong to different levels having different values of n.

So, their angular momenta will be different, as

$$L = mvr = \frac{nh}{2\pi}$$

Q. 3. Define ionization energy. How would the ionization energy change when electron in hydrogen atom is replaced by a particle of mass 200 times than that of the electron but having the same charge? *[CBSE Central 2016]*

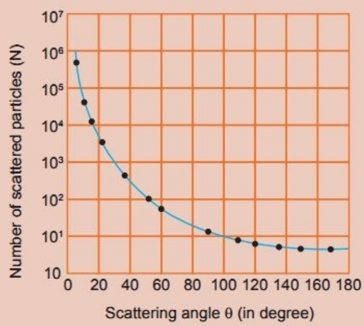
Ans. The minimum energy required to free the electron from the ground state of the hydrogen atom is known as ionization energy.

$$E_0 = \frac{me^4}{8\,\varepsilon^2 h^2}, \quad i.e., E_0 \propto m$$

Therefore, ionization energy will become 200 times.

Q. 4. Draw the graph showing the variation of the number (N) of scattered alpha particles with scattering angle (θ) in Geiger – Marsden experiment. Infer two conclusions from the graph. *[CBSE 2022 (55/1/1), Term-2]*

Ans. Graph:



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(Give full credit if axis are marked and values are not given)

Conclusions

- Most of the alpha particles pass undeviated through the gold foil.
- A few alpha particles, get deflected through 90° or more.
- Only about 0.14% of the incident alpha particles are reflected by large angle. ½ + ½
- A very few alpha particles retrace their path.

(Any other two conclusions) *[CBSE Marking Scheme 2022 (55/1/1), Term-2]*

Q. 5. The ground state energy of hydrogen atom is –13.6 eV. What is the potential energy and kinetic energy of an electron in the third excited state? *[CBSE 2023 (55/1/1)]*

Ans. For ground state, Energy (E) = –13.6 eV

For third excited state, $n = 4$,

$$E_4 = \frac{-13.6}{n^2} = \frac{-13.6}{4^2} = -0.85 \text{ eV}$$

$\therefore \quad K.E = -E = -(-0.85) = \mathbf{0.85\ eV}$

and $\quad P.E = -2K.E = -2 \times 0.85 = \mathbf{-1.7\ eV}$.

Q. 6. Use Bohr's model of hydrogen atom to obtain the relationship between the angular momentum and the magnetic moment of the revolving electron. **[*CBSE 2020 (55/5/1)*]**

Ans. According to Bohr's model,

$$L = \text{Angular momentum} = mvr = \frac{nh}{2\pi} \qquad \tfrac{1}{2}$$

$$\mu = \text{Magnetic moment} = \text{current} \times \text{area of the orbit} \qquad \tfrac{1}{2}$$

$$\mu = \frac{|e| \times v}{2\pi r} \times \pi r^2 = \frac{|e| vr}{2} \qquad \left[I = \frac{ev}{2\pi r}\right] \qquad \tfrac{1}{2}$$

Now, $\quad \dfrac{L}{\mu} = \dfrac{mvr \times 2}{|e| vr} = \dfrac{2m}{|e|}$

$$\therefore \quad \mu = \frac{|e|}{2m} L \qquad \tfrac{1}{2}$$

[*CBSE Marking Scheme 2020 (55/5/1)*]

Q. 7. When is H_α line in the emission spectrum of hydrogen atom obtained? Calculate the frequency of the photon emitted during this transition. **[*CBSE North 2016*]**

Ans. The line with the longest wavelength of the Balmer series is called H_α.

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

where λ = wavelength

$$R = 1.097 \times 10^7 \text{ m}^{-1} \text{ (Rydberg constant)}$$

When the electron jumps from the orbit with $n = 3$ to $n = 2$,

We have

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right) \quad \Rightarrow \quad \frac{1}{\lambda} = \frac{5}{36}R$$

The frequency of photon emitted is given by

$$\nu = \frac{c}{\lambda} = c \times \frac{5}{36}R$$

$$= 3 \times 10^8 \times \frac{5}{36} \times 1.097 \times 10^7 \text{ Hz}$$

$$= \mathbf{4.57 \times 10^{14}\ Hz}$$

Q. 8. A difference of 2.3 eV separates two energy levels in an atom. What is the frequency of radiation emitted when the atom makes transition from the upper level to the lower level? **[*NCERT*]**

Ans. According to Bohr's postulate

$$E_1 - E_2 = h\nu$$

$\therefore$ Frequency of emitted radiation

$$\nu = \frac{E_1 - E_2}{h} = \frac{2.3 \text{ eV}}{h}$$

$$= \frac{2.3 \times 1.6 \times 10^{-19} \text{ J}}{6.63 \times 10^{-34} \text{ J–s}} = \mathbf{5.55 \times 10^{14}\ Hz}$$

Q. 9. A hydrogen atom is in its third excited state.

(a) How many spectral lines can he emitted by it before coming to the ground state? Show these transitions in the energy level diagram.

(b) In which of the above transitions will the spectral line of shortest, wavelength be emitted?

[*CBSE 2020 (55/3/1)*]

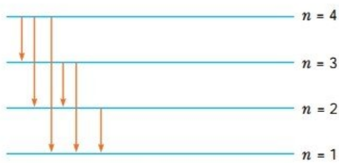
Ans. (a) For third excited state, $n = 4$

For ground state, $n = 1$

Hence, the possible transitions are

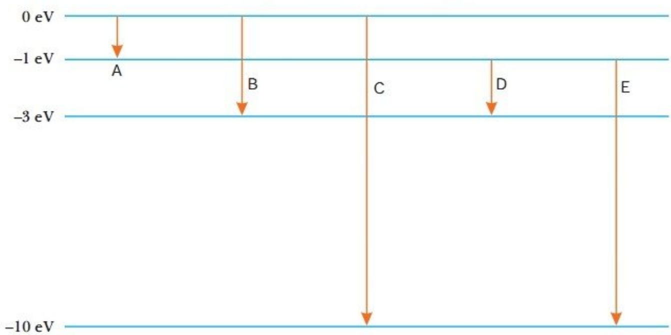
$$n_i = 4 \text{ to } n_f = 3, 2, 1$$
$$n_i = 3 \text{ to } n_f = 2, 1$$
$$n_i = 2 \text{ to } n_f = 1$$

$\therefore$ Total number of transitions = 6, as shown in figure.



(b) The shortest wavelength corresponds to the transition when e^- jumps from $n = 4$ to $n = 1$.

Q. 10. The energy levels of an atom are given below in the diagram.



Which of the transitions belong to Lyman and Balmer series? Calculate the ratio of the shortest wavelengths of the Lyman and the Balmer series of the spectra.

[*CBSE Chennai 2015, CBSE 2019 (55/2/3)*]

Ans. Transition C and E belong to Lyman series.

Reason: In Lyman series, the electron jumps to lowest energy level from any higher energy levels.

Transition B and D belong to Balmer series.

Reason: The electron jumps from any higher energy level to the level just above the ground energy level.

The wavelength associated with the transition is given by

$$\lambda = \frac{hc}{\Delta E}$$

Ratio of the shortest wavelength

$$\lambda_L : \lambda_B = \frac{hc}{\Delta E_L} : \frac{hc}{\Delta E_B}$$

$$= \frac{1}{0-(-10)} : \frac{1}{0-(-3)} = \mathbf{3:10}$$

Q. 11. Using Bohr's atomic model, derive the expression for the radius of n^{th} orbit of the revolving electron in a hydrogen atom. *[CBSE 2020 (55/1/1), 2023 (55/3/1)]*

Ans. Centripetal force required by electron to revolve = Electrostatic attraction of nucleus and electron

$$F_C = F_E$$

$$\Rightarrow \quad \frac{mv_n^2}{r_n} = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{(Ze)(e)}{r_n^2} \qquad (m = \text{mass of electron})$$

$$\Rightarrow \quad mv_n^2 r_n = \frac{e^2}{4\pi\varepsilon_0} \qquad [\because Z = 1 \text{ for H-atom}] \qquad ...(i)$$

According to Bohr's second postulate,

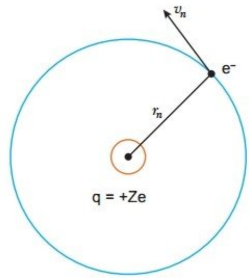
Angular momentum of electron, $L = mv_n r_n = \frac{nh}{2\pi}$ ...(*ii*)

From (*ii*) $v_n = \frac{nh}{2\pi m r_n}$

From (*i*), we have

$$\Rightarrow \quad mr_n\left(\frac{nh}{2\pi m r_n}\right)^2 = \frac{e^2}{4\pi\varepsilon_0}$$

$$\Rightarrow \quad r_n = \frac{n^2 h^2 \varepsilon_0}{m\pi e^2}$$



Q. 12. A photon emitted during the de-excitation of electron from a state *n* to the first excited state in a hydrogen atom, irradiates a metallic cathode of work function 2 eV, in a photo cell, with a stopping potential of 0.55 V. Obtain the value of the quantum number of the state *n*. *[CBSE 2019 (55/2/1)]*

Ans. From photoelectric equation,

$$h\nu = \phi_0 + eV_s$$

$$= 2 + 0.55 = 2.55 \text{ eV}$$

Given, $\quad E_n = -\frac{13.6}{n^2}$

The energy difference, $\Delta E = -3.4 - (-2.55) \text{ eV} = -0.85 \text{ eV}$

$$-\frac{13.6}{n^2} = -0.85$$

$\therefore \quad$ $\mathbf{n = 4}$

Q. 13. The energy of hydrogen atom in an orbit is –1.51 eV. What are kinetic and potential energies of the electron in this orbit? *[CBSE 2022 (55/3/3), Term–2]*

Ans.

From Bohr's postulate, we have.
~~We have~~

$\frac{Ke^2}{r^2} = \frac{mv^2}{r}$ [1st postulate]

[Electrostatic force applies the required centripetal force]

$K = \frac{1}{4\pi\varepsilon_0} = 9\times10^9$

$e \Rightarrow$ charge of electron
$r \Rightarrow$ radius of orbit
$m \Rightarrow$ mass of electrons
$v \Rightarrow$ velocity of electrons in the orbit.

$\Rightarrow mv^2 = \frac{Ke^2}{r}$

Now Kinetic energy of electron in an orbit (KE) $= \frac{1}{2}mv^2 = \boxed{\frac{Ke^2}{2r}} = KE$

Potential energy of electron in the orbit (PE) $= \frac{K(e)(-e)}{r} = \boxed{-\frac{Ke^2}{r}} = P.E.$

Total energy of electron (TE) = PE + KE

$\Rightarrow TE = -\frac{Ke^2}{r} + \frac{Ke^2}{2r}$

$\boxed{TE = -\frac{Ke^2}{2r}}$

Given that energy of electron in Hydrogen atom is $= -1.51eV$
$= -\frac{Ke^2}{2r}$

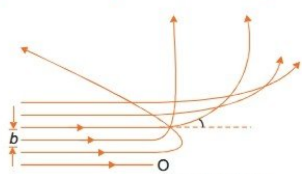
$\Rightarrow \frac{Ke^2}{r} = 3.02 eV$

$\Rightarrow PE = -\frac{Ke^2}{r} = -3.02 eV$, $KE = \frac{Ke^2}{2r} = +1.51 eV$

Ans. Thus, $\boxed{\begin{array}{l} KE = +1.51 eV \\ PE = -3.02 eV \end{array}}$

[*Topper's Answer 2022*]

Q. 14. The trajectories, traced by different α-particles, in Geiger-Marsden experiment were observed as shown in the figure. [*CBSE 2020 (55/2/1)*]



(*a*) **What names are given to the symbols '*b*' and 'θ' shown here?**

(*b*) **What can we say about the values of *b* for (*i*) $\theta = 0°$ (*ii*) $\theta = \pi$ radians?**

Ans. (*a*) The symbol '*b*' represents **impact parameter** and 'θ' represents the **scattering angle**.

(*b*) (*i*) When $\theta = 0°$, the **impact parameter** will be maximum and represent the **atomic size.**

(*ii*) When $\theta = \pi$ radians, the impact parameter '*b*' will be minimum and represent the nuclear size.

Q. 15. Which is easier to remove: orbital electron from an atom or a nucleon from a nucleus? [*HOTS*]

Ans. It is easier to remove an orbital electron from an atom. The reason is the binding energy of orbital electron is a few electron-volts while that of nucleon in a nucleus is quite large (nearly 8 MeV). This means that the removal of an orbital electron requires few electron volt energy while the removal of a nucleon from a nucleus requires nearly 8 MeV energy.

Q. 16. Write shortcomings of Rutherford atomic model. Explain how these were overcome by the postulates of Bohr's atomic model. **[*CBSE 2020 (55/5/1)*]**

Ans. Two important limitations of Rutherford model are:

(*i*) According to Rutherford model, electron orbiting around the nucleus, continuously radiates energy due to the acceleration; hence the atom will not remain stable.

(*ii*) As electron spirals inwards; its angular velocity and frequency change continuously, therefore it should emit a continuous spectrum.

But an atom like hydrogen always emits a discrete line spectrum.

Bohr's postulates overcome these limitations by:

(*i*) Bohr stated that negatively charged electrons revolve around positively charged nucleus in certain orbits called stationary orbits. The electrons does not radiate energy when in stationary orbits.

(*ii*) The quantum of energy is released or absorbed when an electron jumps from one stationary orbit to another.

Q. 17. Find the ratio of the longest and the shortest wavelengths amongst the spectral lines of Balmer series in the spectrum of hydrogen atom. **[*CBSE 2020 (55/4/1)*]**

Ans. For shortest wave length,

$$\frac{1}{\lambda_S} = R\left(\frac{1}{2^2} - \frac{1}{\infty}\right)$$

$$\frac{1}{\lambda_S} = \frac{R}{4} \qquad \ldots(i) \qquad \tfrac{1}{2}$$

For longest wave length,

$$\frac{1}{\lambda_L} = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right)$$

$$= R\left(\frac{1}{4} - \frac{1}{9}\right)$$

$$= R\left(\frac{5}{36}\right) \qquad \ldots(ii) \qquad \tfrac{1}{2}$$

Dividing equation (*i*) by equation (*ii*) we get,

$$\frac{\left(\frac{1}{\lambda_S}\right)}{\left(\frac{1}{\lambda_L}\right)} = \frac{\left(\frac{R}{4}\right)}{\left(\frac{5R}{36}\right)} \qquad \tfrac{1}{2}$$

$$\therefore \qquad \frac{\lambda_L}{\lambda_S} = \frac{9}{5} \Rightarrow \lambda_L : \lambda_S = 9:5 \qquad \tfrac{1}{2}$$

[*CBSE Marking Scheme 2020 (55/4/1)*]

Short Answer Questions

Each of the following questions are of 3 marks.

Q. 1. (*i*) State Bohr postulate of hydrogen atom that gives the relationship for the frequency of emitted photon in a transition.

(*ii*) An electron jumps from fourth to first orbit in an atom. How many maximum number of spectral lines can be emitted by the atom? To which series these lines correspond? [*CBSE (F) 2016*]

Ans. (*i*) **Bohr's third postulate:** It states that an electron might make a transition from one of its specified non-radiating orbits to another of lower energy. When it does so, a photon is emitted having energy equal to the energy difference between the initial and final states. The frequency of the emitted photon is given by

$$h\nu = E_i - E_f$$

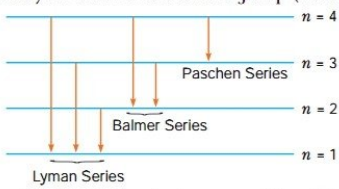
where E_i and E_f are the energies of the initial and final states and $E_i > E_f$.

(*ii*) Electron jumps from fourth to first orbit in an atom

$\therefore$ Maximum number of spectral lines can be

$$^4C_2 = \frac{4!}{2!2!} = \frac{4 \times 3}{2} = 6$$

In diagram, possible way in which electron can jump (above).



The line responds to Lyman series (e^- jumps to 1st orbit), Balmer series (e^- jumps to 2nd orbit), Paschen series (e^- jumps to 3rd orbit).

Q. 2. Calculate the de-Broglie wavelength associated with the electron revolving in the first excited state of hydrogen atom. The ground state energy of the hydrogen atom is –13.6 eV.

[*CBSE 2020 (55/5/1)*]

Ans. Energy of the electron in the first excited state,

$$E_I = \frac{13.6}{2^2}\text{eV} = 3.4 \text{ eV} = -3.4 \times 1.6 \times 10^{-19}\text{J} = -5.44 \times 10^{-19}\text{J} \qquad \tfrac{1}{2} + \tfrac{1}{2}$$

Associated kinetic energy $= -E_1$ ½

$$K = 5.44 \times 10^{-19}\text{J} \qquad \tfrac{1}{2}$$

$\therefore$ de-Broglie wavelength, $\lambda = h/p$

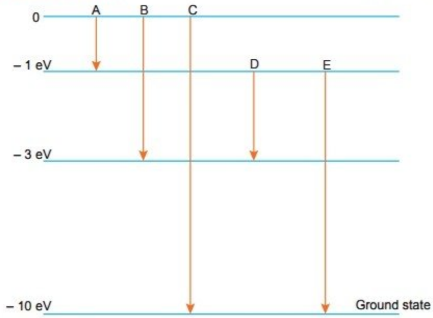
$$\lambda = \frac{h}{\sqrt{2mK}} = \frac{6.63 \times 10^{-34}}{(2 \times 9.1 \times 10^{-31} \times 5.44 \times 10^{-19})^{1/2}}\text{ m} \qquad \tfrac{1}{2}$$

$$= \frac{6.63 \times 10^{-34}}{(99.008)^{1/2} \times 10^{-25}}\text{ m}$$

$$\approx 0.663 \times 10^{-9}\text{ m} = 0.663 \text{ nm} = 6.63 \text{ Å} \qquad \tfrac{1}{2}$$

[*CBSE Marking Scheme 2020 (55/5/1)*]

Q. 3. The energy levels of an atom of element X are shown in the diagram. Which one of the level transitions will result in the emission of photons of wavelength 620 nm? Support your answer with mathematical calculations. **[*CBSE Sample Question Paper 2018*]**



Ans. Eergy of Photon, $E = \dfrac{hc}{\lambda}$

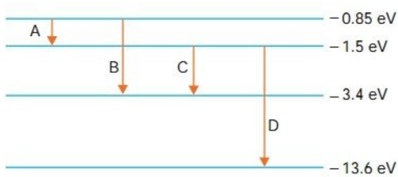
$$= \frac{6.6\times10^{-34}\times3\times10^{8}}{620\times10^{-9}}$$

$$= 3.2 \times 10^{-19}\,\text{J}$$

$$= \frac{3.2\times10^{-19}}{1.6\times10^{-19}} = \mathbf{2\ eV}$$

This corresponds to the transition '*D*'. Hence level transition *D* will result in emission of wavelength 620 nm.

Q. 4. The energy level diagram of an element is given below. Identify, by doing necessary calculations, which transition corresponds to the emission of a spectral line of wavelength 102.7 nm. **[*CBSE Delhi 2008*]**



Ans. We have, $\Delta E = \dfrac{hc}{\lambda} = \dfrac{6.6\times10^{-34}\times3\times10^{8}}{102.7\times10^{-9}}\,\text{J}$

$$= \frac{6.6\times10^{-34}\times3\times10^{8}}{102.7\times10^{-9}\times1.6\times10^{-19}}\,\text{eV}$$

$$= \frac{66\times3000}{1027\times16} = 12.04\ \text{eV}$$

Now, $\Delta E = |-13.6 - (-1.50)|$

$$= \mathbf{12.1\ eV}$$

Hence, transition shown by arrow *D* corresponds to emission of $\lambda = 102.7$ nm.

Q. 5. Determine the distance of closest approach when an alpha particle of kinetic energy 4.5 MeV strikes a nucleus of Z = 80, stops and reverses its direction. **[*CBSE Ajmer 2015*]**

Ans. Let r be the centre to centre distance between the alpha particle and the nucleus (Z = 80). When the alpha particle is at the stopping point, then

$$K = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(2e)}{r}$$

or $$r = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2Ze^2}{K}$$

$$= \frac{9\times10^9\times2\times80\,e^2}{4.5\,\text{MeV}} = \frac{9\times10^9\times2\times80\times(1.6\times10^{-19})^2}{4.5\times10^6\times1.6\times10^{-19}}$$

$$= \frac{9\times160\times1.6}{4.5}\times10^{-16} = 512\times10^{-16}\,\text{m}$$

$$= \mathbf{5.12\times10^{-14}\,m}$$

Q. 6. Derive an expression for the frequency of radiation emitted when a hydrogen atom de-excites from level n to level $(n - 1)$. Also show that for large values of n, this frequency equals to classical frequency of revolution of an electron. **[*CBSE Sample Paper 2022, Term–2*]**

Ans. From Bohr's theory, the frequency f of the radiation emitted when an electron de – excites from level n_2 to level n_1 is given as

$$f = \frac{2\pi^2 mk^2Z^2e^4}{h^3}\left[\frac{1}{n_1^{\,2} - n_2^{\,2}}\right]$$

Given $n_1 = n - 1$, $n_2 = n$, derivation of it

$$f = \frac{2\pi^2 mk^2Z^2e^4}{h^3}\frac{(2n-1)}{(n-1)^2n^2}$$

For large n, $2n - 1 = 2n$, $n - 1 = n$ and $Z = 1$.

Thus, $$f = \frac{4\pi^2 mk^2e^4}{n^3h^3}$$

which is same as orbital frequency of electron in n^{th} orbit.

$$f = \frac{v}{2\pi r} = \frac{4\pi^2 mk^2e^4}{n^3h^3}$$

Q. 7. The ground state energy of hydrogen atom is – 13.6 eV. If an electron makes a transition from an energy level – 1.51 eV to – 3.4 eV, calculate the wavelength of the spectral line emitted and name the series of hydrogen spectrum to which it belongs. **[*CBSE (AI) 2017*]**

Ans.

$E_1 = -13{\cdot}6\,\text{eV}$

$E_i = -1{\cdot}51\,\text{eV}$

$E_f = -3{\cdot}4\,\text{eV}$

change in energy $= E_i - E_f = -1{\cdot}51\,\text{eV} - 3{\cdot}4\,\text{eV}$

$= 3{\cdot}4\,\text{eV} - 1{\cdot}51\,\text{eV}$

$= \underline{1{\cdot}89\,\text{eV}}$

$h\nu = 1{\cdot}89\,\text{eV}$

$\frac{hc}{\lambda} = 1{\cdot}89\times1{\cdot}6\times10^{-19}\,\text{J}$

$\lambda = \frac{hc}{1{\cdot}89\times1{\cdot}6\times10^{-19}\,\text{J}} = \frac{6{\cdot}636\times10^{-34}\times3\times10^{8}\,\text{m s}^{-1}\,\text{kg m}^2\text{s}^{-1}}{1{\cdot}89\times1{\cdot}6\times10^{-19}\,\text{kg m}^2\text{s}^{-2}}$

$$\frac{19.908 \times 10^{-26}\ \text{m}}{30.24 \times 10^{-1} \times 10^{-19}}$$

$$\frac{19.908 \times 10^{-26}\ \text{m}}{3.024 \times 10^{-19}}$$

$$= 6.58 \times 10^{-7}\ \text{m}$$

$$= 6.58 \times 10^{-7}\ \text{m}.$$

It belongs to visible light and hence it belongs to Balmer series of Hydrogen spectrum

Since 658 nm belongs to 400 nm to 700 nm.

6.636, 19.908, $302\overline{)1990}$

[*Topper's Answer 2017*]

Q. 8. A hydrogen atom initially in its ground state absorbs a photon and is in the excited state with energy 12.5 eV. Calculate the longest wavelength of the radiation emitted and identify the series to which it belongs.

[Take Rydberg constant $R = 1.1 \times 10^7\ \text{m}^{-1}$] **[*CBSE East 2016*]**

Ans. Let n_i and n_f are the quantum numbers of initial and final states, then we have

$$\frac{1}{\lambda_{max}} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

The energy of the incident photon = 12.5 eV.

Energy of ground state = –13.6 eV

$\therefore$ Energy after absorption of photon can be –1.1 eV.

This means that electron can go to the excited state $n_i = 3$. It emits photon of maximum wavelength on going to $n_f = 2$, therefore,

$$\frac{1}{\lambda_{max}} = \left\{\frac{1}{2^2} - \frac{1}{3^2}\right\}R$$

$$\lambda_{max} = \frac{36}{5R} = \frac{36}{5 \times 1.1 \times 10^7} = 6.545 \times 10^{-7}\ \text{m} = \mathbf{6545\ Å}$$

It belongs to Balmer Series.

Q. 9. A 12.5 eV electron beam is used to excite a gaseous hydrogen atom at room temperature. Determine the wavelengths and the corresponding series of the lines emitted.[*CBSE (AI) 2017*]

Ans. It is given that the energy of the electron beam used to bombard gaseous hydrogen at room temperature is 12.5 eV.

Also, the energy of the gaseous hydrogen in its ground state at room temperature is –13.6 eV.

When gaseous hydrogen is bombarded with an electron beam, the energy of the gaseous hydrogen becomes –13.6 + 12.5 eV = –1.1 eV.

Orbital energy related to orbit level (n) is

$$E = \frac{-13.6}{(n)^2}\text{eV}$$

For $n = 3$,

$$E = \frac{-13.6}{(3)^2}\text{eV} = \frac{-13.6}{9}\text{eV} = -1.5\ \text{eV}$$

This energy is approximately equal to the energy of gaseous hydrogen.

This implies that the electron has jumped from $n = 1$ to $n = 3$ level.

During its de-excitation, electrons can jump from $n = 3$ to $n = 1$ directly, which forms a line of the Lyman series of the hydrogen spectrum.

Relation for wave number for the Lyman series is

$$\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{n^2}\right]$$

For first member $n = 3$

$$\therefore \quad \frac{1}{\lambda_1} = R\left[\frac{1}{1^2} - \frac{1}{(3)^2}\right] = R\left[\frac{1}{1} - \frac{1}{9}\right]$$

$$\therefore \quad \frac{1}{\lambda_1} = 1.097 \times 10^7\left[\frac{9-1}{9}\right] \quad \text{(where Rydberg constant } R = 1.097 \times 10^7 \text{ m}^{-1}\text{)}$$

$$\therefore \quad \frac{1}{\lambda_1} = 1.097 \times 10^7 \times \frac{8}{9} \quad \Rightarrow \quad \boldsymbol{\lambda_1 = 1.025 \times 10^{-7}\ \mathrm{m}}$$

For $n = 2$,

$$\therefore \quad \frac{1}{\lambda_2} = R\left[\frac{1}{1^2} - \frac{1}{(2)^2}\right] = R\left[\frac{1}{1} - \frac{1}{4}\right]$$

$$\therefore \quad \frac{1}{\lambda_2} = 1.097 \times 10^7\left[\frac{4-1}{4}\right]$$

$$\therefore \quad \frac{1}{\lambda_2} = 1.097 \times 10^7 \times \frac{3}{4} \quad \Rightarrow \quad \boldsymbol{\lambda_2 = 1.215 \times 10^{-7}\,\mathrm{m}}$$

Relation for wave number for the Balmer series is

$$\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{n^2}\right]$$

For first member, $n = 3$

$$\therefore \quad \frac{1}{\lambda_3} = R\left[\frac{1}{2^2} - \frac{1}{3^2}\right] = 1.097 \times 10^7 \times \left[\frac{1}{4} - \frac{1}{9}\right]$$

$$\Rightarrow \quad \boldsymbol{\lambda_3 = 6.56 \times 10^{-7}\ \mathrm{m}}$$

Q. 10. Obtain the first Bohr's radius and the ground state energy of a muonic hydrogen atom, *i.e.*, an atom where the electron is replaced by a negatively charged muon (μ^-) of mass about 207 m_e that orbits around a proton.

(Given for hydrogen atom, radius of first orbit and ground state energy are 0.53×10^{-10} m and – 13.6 eV respectively) ***[CBSE 2019 (55/5/1)]***

Ans. In Bohr's Model of hydrogen atom the radius of nth orbit is given by

$$r_n = \frac{n^2h^2}{4\pi^2e^2m_e} \qquad \text{[for H-atom, } Z = 1\text{]}$$

$$r_1 \propto \frac{1}{m_e} \qquad (\because n = 1)$$

Similarly,

$$r_\mu \propto \frac{1}{m_\mu}$$

$$\frac{r_\mu}{r_e} = \frac{m_e}{m_\mu} = \frac{1}{207} \quad \Rightarrow \quad r_\mu = \frac{1}{207}r_e = \frac{0.53 \times 10^{-10}}{207} = 2.56 \times 10^{-13}\,\mathrm{m}$$

Energy of electron in nth orbit,

$$E_n = -\frac{Z^2 me^4}{8E_0 h^2 n^2} \qquad \Rightarrow E_n \propto m \qquad (\because n = 1)$$

and
$$\frac{E_\mu}{E_e} = \frac{m_\mu}{m_e} = 207$$

$\therefore$
$$E_\mu = 207\, E_e = -207 \times 13.6 \text{ eV}$$
$$= \mathbf{-2.8 \text{ keV}}$$

Q. 11. A hydrogen atom initially in the ground state absorbs a photon, which excites it to the n=4 level. Determine the wavelength and frequency of photon. [*NCERT*]

Ans. The energy levels of H-atom are given by $E_n = -\frac{Rhc}{n^2}$

For given transition $n_1 = 1, n_2 = 4$

$\therefore$
$$E_1 = -\frac{Rhc}{1^2}, \quad E_2 = -\frac{Rhc}{4^2}$$

$\therefore$ Energy of absorbed photon

$$\Delta E = E_2 - E_1 = Rhc\left(\frac{1}{1^2} - \frac{1}{4^2}\right)$$

or
$$\Delta E = \frac{15}{16} Rhc$$

$\therefore$ Wavelength of absorbed photon λ is given by

$$\Delta E = \frac{hc}{\lambda}$$

$\therefore$
$$\frac{hc}{\lambda} = \frac{15}{16} Rhc \quad \Rightarrow \quad \lambda = \frac{16}{15R}$$

or
$$\lambda = \frac{16}{15 \times 1.097 \times 10^7} \text{m} = \mathbf{9.72 \times 10^{-8} \text{ m}}$$

Frequency,
$$\nu = \frac{c}{\lambda} = \frac{3 \times 10^8}{9.72 \times 10^{-8}} = \mathbf{3.09 \times 10^{15} \text{ Hz}}$$

Long Answer Questions

Each of the following questions are of 5 marks.

Q. 1. Draw a schematic arrangement of Geiger-Marsden experiment for studying α-particle scattering by a thin foil of gold. Describe briefly, by drawing trajectories of the scattered α-particles. How this study can be used to estimate the size of the nucleus? [*CBSE Delhi 2010*]

OR

Describe Geiger-Marsden experiment. What are its observations and conclusions?

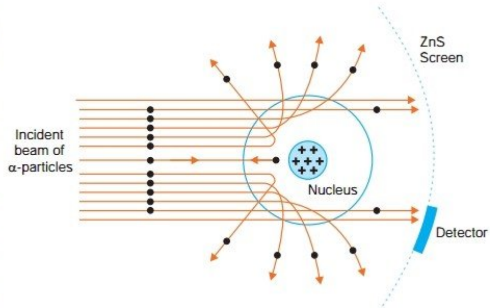
Ans. At the suggestion of Rutherford, in 1911, H. Geiger, and E. Marsden performed an important experiment called Geiger-Marsden experiment (or Rutherford's scattering experiment). It consists of

1. **Source of α-particles:** The radioactive source polonium emits high energetic alpha (α) particles. Therefore, polonium is used as a source of α-particles. This source is placed in an enclosure containing a hole and a few slits $A_1, A_2, \ldots$, etc., placed in front of the hole. This arrangement provides a fine beam of α-particles.

2. **Thin gold foil:** It is a gold foil of thickness nearly 10^{-6} m, α-particles are scattered by this foil. The foil taken is thin to avoid multiple scattering of α-particles, *i.e.*, to ensure that α-particle be deflected by a single collision with a gold atom.
3. **Scintillation counter:** By this the number of α-particles scattered in a given direction may be counted. The entire apparatus is placed in a vacuum chamber to prevent any energy loss of α-particles due to their collisions with air molecules.

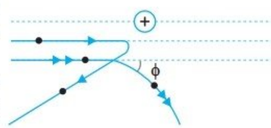
Method: When α-particle beam falls on gold foil, the α-particles are scattered due to collision with gold atoms. This scattering takes place in all possible directions. The number of α-particles scattered in any direction is counted by scintillation counter.

Observations and Conclusions



(*i*) Most of α-particles pass through the gold foil undeflected. This implies that "most part of the atom is hollow."

(*ii*) α-particles are scattered through all angles. Some α-particles (nearly 1 in 2000), suffer scattering through angles more than 90°, while a still smaller number (nearly 1 in 8000) retrace their path. This implies that when fast moving positively charged α-particles come near gold-atom, then a few of them experience such a strong repulsive force that they turn back. On this basis Rutherford concluded that whole of positive charge of atom is concentrated in a small central core, called the nucleus.



The distance of closest approach of α-particle gives the estimate of nuclear size. If Ze is charge of nucleus, E_k–kinetic energy of α particle, $2e$–charge on α-particle, the size of nucleus r_0 is given by

$$E_k = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(2e)}{r_0} \qquad \Rightarrow \qquad r_0 = \frac{1}{4\pi\varepsilon_0}\frac{2Ze^2}{E_k}$$

Calculations show that the size of nucleus is of the order of 10^{-14} m, while size of atom is of the order of 10^{-10}m; therefore the size of nucleus is about $\frac{10^{-14}}{10^{-10}} = \frac{1}{10,000}$ times the size of atom.

(*iii*) The negative charges (electrons) do not influence the scattering process. This implies that nearly whole mass of atom is concentrated in nucleus.

Q. 2. Using the postulates of Bohr's model of hydrogen atom, obtain an expression for the frequency of radiation emitted when atom make a transition from the higher energy state with quantum number n_i to the lower energy state with quantum number n_f ($n_f < n_i$). [*CBSE (AI) 2013, (F) 2012, 2011*]

OR

Using Bohr's postulates, obtain the expression for the total energy of the electron in the stationary states of the hydrogen atom. Hence draw the energy level diagram showing how the line spectra corresponding to Balmer series occur due to transition between energy levels.
[*CBSE Delhi 2013, Guwahati 2015*]

OR

Using Rutherford model of the atom, derive the expression for the total energy of the electron in hydrogen atom. What is the significance of total negative energy possessed by the electron? [*CBSE (AI) 2014*]

Ans. Suppose m be the mass of an electron and v be its speed in nth orbit of radius r. The centripetal force for revolution is produced by electrostatic attraction between electron and nucleus.

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(e)}{r^2} \qquad \text{[from Rutherford model]} \qquad \ldots(i)$$

or, $$mv^2 = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r}$$

So, Kinetic energy $[K] = \frac{1}{2}mv^2 = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{2r}$

Potential energy $= \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(-e)}{r} = -\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r}$

Total energy, $$E = KE + PE = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{2r} + \left(-\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r}\right) = -\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{2r}$$

For nth orbit, $$E_n = -\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{2r_n} \qquad \ldots(ii)$$

Negative sign indicates that the electron remains bound with the nucleus (or electron-nucleus form an attractive system)

From Bohr's postulate for quantization of angular momentum

$$mvr = \frac{nh}{2\pi} \Rightarrow v = \frac{nh}{2\pi mr}$$

Substituting this value of v in equation (i), we get

$$\frac{m}{r}\left[\frac{nh}{2\pi mr}\right]^2 = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r^2} \quad \text{or} \quad r = \frac{\varepsilon_0 h^2 n^2}{\pi m Ze^2}$$

or, $$r_n = \frac{\varepsilon_0 h^2 n^2}{\pi m Ze^2}$$

For Bohr's radius, $n = 1$, *i.e.*, for K shell $r_B = \frac{\varepsilon_0 h^2}{\pi Z me^2}$

Substituting value of r_n in equation (ii), we get

$$E_n = -\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{2\left(\frac{\varepsilon_0 h^2 n^2}{\pi m Ze^2}\right)} = -\frac{mZ^2e^4}{8\varepsilon_0^2 h^2 n^2}$$

or, $$E_n = -\frac{Z^2 Rhc}{n^2}, \text{ where } R = \frac{me^4}{8\varepsilon_0^2 ch^3}$$

R is called Rydberg constant.

For hydrogen atom $Z=1$, $E_n = \frac{-Rhc}{n^2}$

If n_i and n_f are the quantum numbers of initial and final states and E_i & E_f are energies of electron in H-atom in initial and final state, we have

$$E_i = \frac{-Rhc}{n_i^2} \text{ and } E_f = \frac{-Rch}{n_f^2}$$

If ν is the frequency of emitted radiation, we get

$$\nu = \frac{E_i - E_f}{h} \quad \Rightarrow \quad \nu = \frac{-Rc}{n_i^2} - \left(\frac{-Rc}{n_f^2}\right) \Rightarrow \nu = Rc\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$$

For Balmer series $n_f = 2$, while $n_i = 3, 4, 5, \ldots\infty$.

Q. 3. Derive the expression for the magnetic field at the site of a point nucleus in a hydrogen atom due to the circular motion of the electron. Assume that the atom is in its ground state and give the answer in terms of fundamental constants. *[CBSE Sample Paper 2016]*

Ans. To keep the electron in its orbit, the centripetal force on the electron must be equal to the electrostatic force of attraction. Therefore,

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2} \quad \text{(For H atom, } Z = 1) \qquad ...(i)$$

From Bohr's quantisation condition

$$mvr = \frac{nh}{2\pi} \Rightarrow v = \frac{h}{2\pi mr} \quad \text{(For } K \text{ shell, } n=1) \qquad ...(ii)$$

From (*i*) and (*ii*), we have

$$\frac{m}{r}\left(\frac{h}{2\pi mr}\right)^2 = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$$

$$\frac{m}{r}\frac{h^2}{4\pi^2 m^2 r^2} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2} \Rightarrow r = \frac{\varepsilon_0 h^2}{\pi m e^2} \qquad ...(iii)$$

From (*ii*) and (*iii*), we get, $v = \frac{h \times \pi m e^2}{2\pi m \varepsilon_0 h^2} = \frac{e^2}{2\varepsilon_0 h}$

Magnetic field at the centre of a circular loop, $B = \frac{\mu_0 I}{2r}$

$\therefore \qquad I = \frac{ev}{2\pi r} \qquad \left[\because I = \frac{Charge}{Time} \text{ and } Time = \frac{2\pi r}{v}\right]$

So, $$B = \frac{\mu_0 ev}{2r \times 2\pi r} = \frac{\mu_0 ev}{4\pi r^2} \qquad ...(iv)$$

From (*ii*), (*iii*) (*iv*), we have

$$B = \frac{\mu_0 e.e^2\pi^2 m^2 e^4}{2\varepsilon_0 h \times 4\pi \times \varepsilon_0^2 h^4} \Rightarrow B = \frac{\mu_0 e^7 \pi m^2}{8\varepsilon_0^{\,3} h^5}$$

Questions for Practice

1. Choose and write the correct option in the following questions.

(*i*) As per Bohr model, the minimum energy (in eV) required to remove an electron from the ground state of doubly-ionised Li atom (Z = 3) is

(*a*) 1.51 (*b*) 13.6 (*c*) 40.8 (*d*) 122.4

(*ii*) The ratio of kinetic energy to the total energy of an electron in a Bohr orbit of the hydrogen atom, is

(*a*) 1 : 1 (*b*) 1 : –1 (*c*) 2 : –1 (*d*) 1 : –2

(*iii*) The ratio of maximum frequency and minimum frequency of light emitted in Balmer series of hydrogen spectrum, in Bohr's model is **[CBSE 2023 (55/3/1)]**

(*a*) $\frac{11}{9}$ (*b*) $\frac{9}{5}$ (*c*) $\frac{11}{7}$ (*d*) $\frac{16}{7}$

(*iv*) In which region of the electromagnetic spectrum does the Lyman series of hydrogen lie?

(*a*) Ultraviolet (*b*) Infra-red (*c*) Visible (*d*) X-ray

(*v*) What is the relation between orbit radius '*r*' and orbit number '*n*' of electron in an atom according to Bohr's theory?

(*a*) $r \propto n^{-1}$ (*b*) $r \propto n$ (*c*) $r \propto n^{-2}$ (*d*) $r \propto n^2$

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

   (*a*) ***Both A and R are true and R is the correct explanation of A.***

   (*b*) ***Both A and R are true but R is not the correct explanation of A.***

   (*c*) ***A is true but R is false.***

   (*d*) ***A is false and R is also false.***

   Assertion (*A*) : Hydrogen atom consists of only one electron but its emission spectrum has many lines.

   Reason (*R*) : Only Lyman series is found in the absorption spectrum of hydrogen atom whereas in the emission spectrum, all the series are found.

3. When electron in hydrogen atom jumps from energy state $n_i = 4$ to $n_f = 3, 2, 1$, identify the spectral series to which the emission lines belong.

4. The energy of electron in *n*th orbit of H-atom is $E_n = -\frac{13.6}{n^2}$ eV. What is the energy required for transition from ground state to first excited state?

5. Define ionisation energy. What is its value for a hydrogen atom? **[*CBSE 2023 (55/2/1)*]**

6. A hydrogen atom initially in the ground state absorbs a photon which excites it to the $n = 4$ level. Estimate the frequency of the photon.

7. (*i*) Define the terms : 'impact parameter' and distance of closest approach for an α-particle in Geiger-Marsden scattering experiment.

   (*ii*) What will be the value of the impact parameter for scattering angle (*a*) $\theta = 0°$ (*b*) $\theta = 180°$?

   [*CBSE 2022 (55/2/1), Term–2*]

8. Draw graph to show the variation of the number of scattered particlea s detected (*N*) in Geiger-Marsden experiment as a function of scattering angle (θ). **[*CBSE 2023 (55/3/1)*]**

9. The ground state energy of hydrogen atom is – 13.6 eV. If an electron makes a transition from an energy level – 0.85 eV to –3.4 eV, calculate the wavelength of the spectral line emitted. To which series of hydrogen spectrum does this wavelength belong?

10. Derive an expression for the frequency of radiation emitted when a hydrogen atom de-excites from level *n* to level (*n* – 1). Also show that for large values of *n*, this frequency equals to classical frequency of revolution of an electron. **[*CBSE Sample Paper 2021*]**

11. Suppose you are given a chance to repeat the alpha particle scattering experiment using a thin sheet of solid hydrogen in place of gold foil (hydrogen is a solid at temperature below 14 K). What results do you expect? **[*NCERT*]**

12. The ground state energy of hydrogen atom is –13.6 eV. What is the kinetic and potential energies of the electron in the ground and second excited state? **[*CBSE (AI) 2010, 2011, Bhubaneshwar 2015*]**

13. The radius of innermost orbit of a hydrogen atom is 5.3×10^{-11} m. What are the radii of $n=2$ and $n=3$ orbits? **[*NCERT*]**

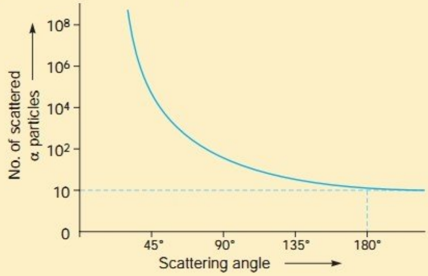
14. In accordance with Bohr's model, find the quantum number, that characterises the earth's revolution around the sun in an orbit of radius 1.5×10^{11} m with orbital speed 3×10^4 m/s. **[*NCERT*]**
    (Mass of earth = 6.0×10^{24} kg)

15. Write two important limitations of Rutherford nuclear model of the atom. **[*CBSE Delhi 2017*]**

16. Find out the wavelength of the electron orbiting in the ground state of hydrogen atom. **[*CBSE Delhi 2017*]**

17. In an experiment on α-(particles) scattering by a thin foil of gold, draw a plot showing the number of particles scattered versus the scattering angle θ.

Why is it that a very small fraction of the particles are scattered at $\theta > 90°$? **[*CBSE (F) 2013*]**



18. A hydrogen atom in the ground state is excited by an electron beam of 12.5 eV energy. Find out the maximum number of lines emitted by the atom from its excited state. **[*CBSE 2019 (55/2/1)*]**

19. A 12.5 eV electron beam is used to excite a gaseous hydrogen atom at room temperature. Determine the wavelengths and the corresponding series of the lines emitted.

20. The spectrum of a star in the visible and the ultraviolet region was observed and the wavelength of some of the lines that could be identified were found to be:

824 Å, 970 Å, 1120 Å, 2504 Å, 5173 Å, 6100 Å

Which of these lines cannot belong to hydrogen atom spectrum? (Given Rydberg constant $R = 1.03 \times 10^7\ \text{m}^{-1}$ and $\frac{1}{R} = 970$ Å). Support your answer with suitable calculations.

21. State Bohr's postulate to explain stable orbits in a hydrogen atom. Prove that the speed with which the electron revolves in nth orbit is proportional to $(1/n)$. **[*CBSE 2022 (55/3/1), Term–2*]**

22. Given the ground state energy $E_0 = -13.6$ eV and Bohr radius $a_0 = 0.53$ Å. Find out how the de Broglie wavelength associated with the electron orbiting in the ground state would change when it jumps into the first excited state.

23. A 12.3 eV electron beam is used to bombard gaseous hydrogen at room temperature. Upto which energy level the hydrogen atoms would be excited?
Calculate the wavelengths of the second member of Lyman series and second member of Balmer series. **[*CBSE Delhi 2014*]**

24. The short wavelength limit for the Lyman series of the hydrogen spectrum is 913.4 Å. Calculate the short wavelength limit for Balmer series of the hydrogen spectrum. **[*CBSE (AI) 2017*]**

Answers

1. (*i*) (*d*) (*ii*) (*b*) (*iii*) (*b*) (*iv*) (*a*) (*v*) (*d*)

2. (*a*) **4.** 10.2 eV **6.** 3.646×10^{-7} m

9. 4853 Å **11.** 2.4 MeV **12.** 13.6 eV, –27.2 eV [For $n = 1$], 1.51eV, –3.02 eV [For $n = 3$]

13. 2.12×10^{-10}m, 4.77×10^{-10}m,

14. 2.57×10^{74} **16.** 3.32 Å **18.** 3 **19.** 6.54×10^{-7}m

23. $n = 3$, 102.5 nm, 486 nm. **24.** 3653.6 Å

13 Nuclei

POINTS TO REMEMBER

1. Composition of Nucleus

The atom consists of central nucleus, containing entire positive charge and almost entire mass. According to accepted model ***the nucleus is composed of protons and neutrons.*** The *proton* was discovered by Rutherford by bombardment of α-particles on nitrogen in accordance with the following equation:

$$\underset{\text{(Nitrogen)}}{{}^{14}_{7}\mathrm{N}} + \underset{(\alpha\text{-particle})}{{}^{4}_{2}\mathrm{He}} \longrightarrow \underset{\text{Oxygen}}{{}^{17}_{8}\mathrm{O}} + \underset{\text{Proton}}{{}^{1}_{1}\mathrm{H}}$$

The superscripts (on the top) denote the *mass number* and subscripts (in the base) denote the *atomic number.* Symbolically a nuclide is written as ${}^{A}_{Z}X$ or ${}_{Z}X^{A}$, where A is the mass number and Z is the atomic number.

The *neutron* was discovered by J. Chadwick by the bombardment of α-particles on beryllium in accordance with

$$\underset{\text{(Beryllium)}}{{}^{9}_{4}\mathrm{Be}} + \underset{(\alpha\text{-particle})}{{}^{4}_{2}\mathrm{He}} \longrightarrow \underset{\text{(Carbon)}}{{}^{13}_{6}\mathrm{C}} + \underset{\text{(Neutron)}}{{}^{1}_{0}n}$$

A neutron is neutral (zero charge) particle and its mass number is 1.

The number of protons in a nucleus is called atomic number (Z) while the number of nucleons (*i.e.*, protons + neutrons) is called the *mass number* (A). In general mass number>atomic number (except for hydrogen nucleus where $A = Z$).

Since neutron is neutral, it is used for artificial disintegration.

2. Size of Nucleus

According to experimental observations, the radius of the nucleus of an atom of mass number A is

$$R = R_0 A^{1/3} \qquad \text{where} \qquad R_0 = 1.2\times10^{-15}\ \text{m} = 1.2\ \text{fm}$$

3. Atomic Masses

The masses of atoms, nuclei, etc., are expressed in terms of atomic mass unit represented by amu or 'u'. For this mass of C-12 atom is taken as standard.

$$1\ \text{u} = \frac{\text{mass of C-12 atom}}{12} = 1.660565\times10^{-27}\ \text{kg}$$

mass of proton (m_p) $= 1.007276$ u

mass of neutron (m_n) $= 1.008665$ u

mass of electron (m_e) $= 0.000549$ u

4. Isotopes, Isobars and Isotones

The nuclides having the same atomic number (Z) but different mass number (A) are called **isotopes**. The nuclides having the same mass number (A), but different atomic number (Z) are called **isobars**. The nuclides having the same number of neutrons ($A–Z$) are called **isotones**.

5. Mass Energy Equivalence Relation

According to Einstein, the mass and energy are equivalent *i.e.*, mass can be converted into energy and vice-versa. The mass energy equivalence relation is $E = mc^2$.

Accordingly, 1 kg mass is equivalent to energy $= 1 \times (3 \times 10^8)^2 = 9 \times 10^{16}$ joules

and $\quad 1 \text{ amu} = \dfrac{1}{6.02 \times 10^{26}}$ kg mass is equivalent to energy 931 MeV.

6. Mass Defect

It is observed that the mass of a nucleus is always less than the mass of constituent nucleons (*i.e.*, protons + neutrons). This difference of *mass* is called the mass defect. Let (Z, A) be the mass of nucleus, m_p = the mass of proton and m_n = mass of neutron, then the mass defect

$$\Delta m = \text{Mass of nucleons} - \text{Mass of nucleus}$$

$$= Zm_p + (A - Z)m_n - M_{\text{nucleus}}$$

7. Binding Energy per Nucleon

This **mass defect** is in the form of binding energy of nucleus, which is responsible for binding the nucleons into a small nucleus.

$\therefore$ Binding energy of nucleus $= (\Delta m)\, c^2$

and $\quad$ Binding energy per nucleon $= \dfrac{(\Delta m)c^2}{A}$

8. Nature of Nuclear Forces

The protons and neutrons inside the nucleus are held together by strong attractive forces. These attractive forces cannot be gravitational since forces on repulsion between protons > > attractive gravitational force between protons. These forces are short range attractive forces called *nuclear forces*. The nuclear forces are strongest in nature, short range and charge independent, therefore the force between proton-proton is the same as the force between neutron-neutron or proton-neutron.

Yukawa tried to explain the existence of these forces, accordingly the proton and neutron do not have independent existence between nucleus. The proton and neutron are interconvertible through negative and positive π-mesons, *i.e.*,

$$\text{Proton} \underset{\pi^+}{\overset{\pi^-}{\rightleftharpoons}} \text{Neutron and Neutron} \xrightarrow{\pi^\circ} \text{Neutron}$$

The existence of meson gives rise to meson field which gives rise to attractive nuclear forces.

The mass of π-meson = 273 × mass of electron.

9. Nuclear Reaction

When a beam of monoenergetic particles (*e.g.*, α-rays, neutrons etc.) collides with a stable nucleus, the original nucleus is converted into a nucleus of new element. This process is called a nuclear reaction. A typical nuclear reaction is

$$a + X \rightarrow Y + b$$

where a is incident energetic particle, X is target nucleus, Y is residual nucleus and b is outgoing particle. This reaction in compact form is expressed as

$$X\,(a, b)\,Y$$

In a nuclear reaction mass number, electric charge, linear momentum, angular momentum and total energy are always conserved. The energy of reaction is

$$Q = (M_a + M_X)\, c^2 - (M_b + M_Y)c^2$$

10. Nuclear Fission

The splitting of heavy nucleus into two or more fragments of comparable masses, with an enormous release of energy is called *nuclear fission*. For example, when slow neutrons are bombarded on $_{92}U^{235}$, the fission takes place according to reaction

$$^{235}_{92}\text{U} + \underset{\text{(slow neutron)}}{^{1}_{0}n} \longrightarrow {}^{141}_{56}\text{Ba} + {}^{92}_{36}\text{Kr} + 3({}^{1}_{0}\text{n}) + 200\,\text{MeV}$$

In nuclear fission the sum of masses before reaction is greater than the sum of masses after reaction, the difference in mass being released in the form of fission energy.

Remarks:

1. It may be pointed out that it is not necessary that in each fission of uranium, the two fragments Ba^{141} and Kr^{92} are formed but they may be any stable isotopes of middle weight atoms. The most probable division is into two fragments containing about 40% and 60% of the original nucleus with the emission of 2 or 3 neutrons per fission.
2. The fission of U^{238} takes place by fast neutrons.

11. Nuclear Fusion

The phenomenon of combination of two or more light nuclei to form a heavy nucleus with release of enormous amount of energy is called *nuclear fusion*. The sum of masses before fusion is greater than the sum of masses after fusion, the difference in mass appearing as fusion energy.

For example, the fusion of two deuterium nuclei into helium is expressed as

$$ {}_1^2\text{H} + {}_1^2\text{H} \longrightarrow {}_2^4\text{He} + 21.6\,\text{MeV}. $$

Thus, fusion process occurs at an extremely high temperature and high pressure as in sun where temperature is 10^7 K.

Remarks:

1. For the fusion to take place, the component nuclei must be brought within a distance of 10^{-14} m. For this they must be imparted high energies to overcome the repulsive force between nuclei. This is possible when temperature is enormously high.
2. The principle of hydrogen bomb is also based in nuclear fusion.
3. The source of energy of sun and other star is *nuclear fusion*. There are two possible cycles:

(*a*) Proton-proton cycle:

$$ {}_1^1\text{H} + {}_1^1\text{H} \longrightarrow {}_1^2\text{H} + {}_1^0\beta + \nu.\ (\text{Neutrino}) + \text{Energy} $$

$$ {}_1^2\text{H} + {}_1^1\text{H} \longrightarrow {}_2^3\text{He} + {}_0^1\text{n} + \text{Energy} $$

$$ {}_2^3\text{He} + {}_2^3\text{He} \longrightarrow {}_2^4\text{He} + {}_1^1\text{H} + {}_1^1\text{H} + \text{Energy} $$

Net result is $ {}_1^1\text{H} + {}_1^1\text{H} + {}_1^1\text{H} + {}_1^1\text{H} \longrightarrow {}_2^4\text{He} + 2\,{}_1^0\beta + 2\nu + \text{Energy (26.7 MeV)}$

(*b*) Carbon-nitrogen cycle:

$$ {}_1^1\text{H} + {}_6^{12}\text{C} \longrightarrow {}_7^{13}\text{N} + \text{Energy} $$

$$ {}_7^{13}\text{N} \longrightarrow {}_6^{13}\text{C} + {}_1^0\beta + \nu\ (\text{neutrino}) $$

$$ {}_6^{13}\text{C} + {}_1^1\text{H} \longrightarrow {}_7^{14}\text{N} + (\text{Energy}) $$

$$ {}_7^{14}\text{N} + {}_1^1\text{H} \longrightarrow {}_8^{15}\text{O} + \text{Energy} $$

$$ {}_8^{15}\text{O} \longrightarrow {}_7^{15}\text{N} + {}_1\beta^0 + \nu\ (\text{neutrino}) $$

$$ {}_7^{15}\text{N} + {}_1^1\text{H} \longrightarrow {}_6^{12}\text{C} + {}_2^4\text{He} + \text{Energy} $$

Net result is $ {}_1^1\text{H} + {}_1^1\text{H} + {}_1^1\text{H} + {}_1^1\text{H} \longrightarrow {}_2^4\text{He} + 2\,{}_1^0\beta + 2\nu + \text{Energy (26.7 MeV)}$

The proton-proton cycle occurs at a relatively lower temperature as compared to carbon-nitrogen cycle which has a greater efficiency at higher temperature.

At the sun whose interior temperature is about 2×10^6 K, the proton-proton cycle has more chances for occurrence.

Multiple Choice Questions

Choose and write the correct option(s) in the following questions.

1. The size of the atom is proportional to

(*a*) A (*b*) $A^{1/3}$ (*c*) $A^{2/3}$ (*d*) $A^{-1/3}$

2. The gravitational force between a H-atom and another particle of mass m will be given by Newton's law: **[*NCERT Exemplar*]**

$F = G\dfrac{M.m}{r^2}$, **where r is in km and**

(*a*) $M = m_{proton} + m_{electron}$

(*b*) $M = m_{proton} + m_{electron} - \dfrac{B}{c^2}\,(B = 13.6\text{ eV})$

(*c*) M is not related to the mass of the hydrogen atom.

(*d*) $M = m_{proton} + m_{electron} - \dfrac{|V|}{c^2}$ ($|V|$ = magnitude of the potential energy of electron in the H-atom).

3. If radius of the $^{27}_{13}\text{Al}$ nucleus is taken to be R_{Al}, then the radius of $^{125}_{53}\text{Te}$ nucleus is nearly

(*a*) $\dfrac{3}{5}R_{\text{Al}}$ (*b*) $\left(\dfrac{13}{53}\right)^{1/3} R_{\text{Al}}$ (*c*) $\left(\dfrac{53}{13}\right)^{1/3} R_{\text{Al}}$ (*d*) $\dfrac{5}{3}R_{\text{Al}}$

4. The mass density of a nucleus of mass number A is **[*CBSE 2023 (55/1/1)*]**

(*a*) proportional to $A^{1/3}$ (*b*) proportional to $A^{2/3}$

(*c*) proportional to A^3 (*d*) independent of A

5. The nuclei of the isotopes of an element contain the same number of a certain particle. What is this particle?

(*a*) Electron (*b*) Neutron (*c*) Nucleon (*d*) Proton

6. How much energy will approximately be released if all the atoms of 1 kg of deuterium could undergo fusion? [Assume energy released per deuterium nucleus is 2 MeV]

(*a*) 2×10^7 kWh (*b*) 9×10^{13} J (*c*) 6×10^{27} calorie (*d*) 9×10^{13} MeV

7. A nuclear reaction is given below. The masses in amu of reactant and product nuclei are given in brackets:

$$\underset{(1.002)}{\text{A}} + \underset{(1.004)}{\text{B}} \longrightarrow \underset{(1.001)}{\text{C}} + \underset{(1.003)}{\text{D}} + \text{Q Mev}$$

The value of energy Q is

(*a*) 1.234 MeV (*b*) 0.91 MeV (*c*) 0.465 MeV (*d*) 1.862 MeV

8. The curve of binding energy per nucleon as a function of atomic mass number has a sharp peak for helium nucleus. This implies that helium nueleus is **[*CBSE 2023 (55/2/1)*]**

(*a*) radioactive (*b*) unstable

(*c*) easily fissionable (*d*) more stable nucleus than its neighbourss

9. Fusion reactions take place at a high temperature because

(*a*) atoms are ionised at high temperature

(*b*) molecules break up at high temperature

(*c*) nuclei break up at high temperature

(*d*) kinetic energy is high enough to overcome repulsion between nuclei

10. **If $M(A, Z)$, M_P and M_n denote the masses of the nucleus $^{A}_{Z}X$, proton and neutron respectively in units of u ($1u = 931.5\ MeV/c^2$) and BE represents its binding energy in MeV, then**

(a) $M(A, Z) = ZM_P + (A - Z) M_n - BE/c^2$
(b) $M(A, Z) = ZM_P + (A - Z) M_n + BE$
(c) $M(A, Z) = ZM_P + (A - Z) M_n - BE$
(d) $M(A, Z) = ZM_P + (A - Z) M_n + BE/c^2$

11. **The average binding energy per nucleon is maximum for the nucleus**

(a) $^{4}_{2}He$ (b) $^{16}_{8}O$ (c) $^{238}_{92}U$ (d) $^{56}_{26}Fe$

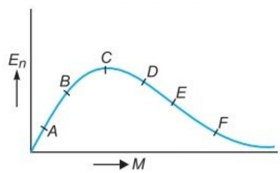
12. **O_2 molecule consists of two oxygen atoms. In the molecule, nuclear force between the nuclei of the two atoms**

(a) is not important because nuclear forces are short-ranged
(b) is as important as electrostatic force for binding the two atoms
(c) cancels the repulsive electrostatic force between the nuclei
(d) is not important because oxygen nucleus have equal number of neutrons and protons

13. **Which of the following statements is not true for the nuclear force?**

(a) It is attractive in nature.
(b) It is charge dependent.
(c) It is short range.
(d) It decreases very quickly with distance between two nucleons.

14. **Fig. shows a plot of binding energy per nucleon E_n against the nuclear mass M. A, B, C, D, E, F correspond to different nuclei. Consider four reactions:** [*HOTS*]



(i) $A + B \rightarrow C + \varepsilon$ (ii) $C \rightarrow A + B + \varepsilon$
(iii) $D + E \rightarrow F + \varepsilon$ (iv) $F \rightarrow D + E + \varepsilon$

where ε is the energy released. In which reaction ε is positive?

(a) (i) and (iv) (b) (i) and (iii) (c) (ii) and (iv) (d) (ii) and (iii)

15. **The energy in nuclear reactor is obtained due to**

(a) nuclear fission (b) nuclear fusion
(c) photoelectric effect (d) spontaneous radioactive decay

16. **Heavy stable nuclei have more neutrons than protons. This is because of the fact that** [*NCERT Exemplar*]

(a) neutrons are heavier than protons.
(b) electrostatic force between protons are repulsive.
(c) neutrons decay into protons through beta decay.
(d) nuclear forces between neutrons are weaker than that between protons.

17. **In a nuclear reactor, moderators slow down the neutrons which come out in a fission process. The moderator used have light nuclei. Heavy nuclei will not serve the purpose because** [*NCERT Exemplar*]

(a) they will break up.
(b) elastic collision of neutrons with heavy nuclei will not slow them down.
(c) the net weight of the reactor would be unbearably high.
(d) substances with heavy nuclei do not occur in liquid or gaseous state at room temperature.

18. Pick out the possible fusion reaction from the following:

(*a*) ${}_6C^{13} + {}_1H^1 \longrightarrow {}_6C^{14} + 4.3\text{ MeV}$

(*b*) ${}_1H^1 \longrightarrow {}_0n^1 + {}_1\beta^0 + \nu$

(*c*) ${}_7N^{14} + {}_1H^1 \longrightarrow {}_8O^{15} + 7.3\text{ MeV}$

(*d*) ${}_{92}U^{235} + {}_0n^1 \longrightarrow {}_{54}Xe^{140} + {}_{38}Sr^{94} + 2({}_0n^1) + \gamma + 200\text{ MeV}$

19. The minimum kinetic energy needed to separate a proton from a nucleus containing Z proton and N neutrons is (m_p = mass of protons)

(*a*) $\left(M_Z^{A-1} + m_n - M_Z^A\right)c^2$

(*b*) $\left(M_Z^{A-1} + m_p - M_Z^A\right)c^2$

(*c*) $\left(M_Z^{A+1} - M_Z^A - m_p\right)c^2$

(*d*) 8 MeV

20. The binding energy per nucleon in ${}_3^7\text{Li}$ and ${}_2^4\text{He}$ are 7.06 MeV and 5.60 MeV respectively, then in the reaction: $p + {}_3^7\text{Li} \to 2\left({}_2^4\text{He}\right)$ the energy of proton must be **[*NCERT Exemplar*]**

(*a*) 28.24 MeV

(*b*) 17.28 MeV

(*c*) 1.46 MeV

(*d*) 39.2 MeV

21. When two nuclei ($A \le 10$) fuse together to form a heavier nucleus, the **[*CBSE 2020 (55/2/1)*]**

(*a*) binding energy per nucleon increases.

(*b*) binding energy per nucleon decreases.

(*c*) binding energy per nucleon does not change.

(*d*) total binding energy decreases.

22. The energy required to release a nucleon from a nucleus is E_n and that required to release an electron from an atom is E_e then

(*a*) $E_n = E_e$

(*b*) $E_n > E_e$

(*c*) $E_n < E_e$

(*d*) may be greater than, equal to or less than depending on the nature of nucleus and atom

23. Fast neutrons can be slowed down by

(*a*) using lead shielding

(*b*) passing them through heavy water

(*c*) elastic collisions with heavy nuclei

(*d*) applying strong electric field

24. Mass of a proton is m_p, mass of a neutron is m_n; mass of ${}_{10}Ne^{20}$ nucleus is M_1 and that of ${}_{20}Ca^{40}$ nucleus in M_2. Then

(*a*) $M_2 = 2\,M_1$

(*b*) $M_2 > 2\,M_1$

(*c*) $M_1 > 10\,(m_n + m_p)$

(*d*) $M_1 < 20\,(m_n + m_p)$

Answers

1. (*b*)	**2.** (*b*)	**3.** (*d*)	**4.** (*d*)	**5.** (*d*)	**6.** (*b*)	**7.** (*d*)
8. (*d*)	**9.** (*d*)	**10.** (*a*)	**11.** (*c*)	**12.** (*a*)	**13.** (*d*)	**14.** (*a*)
15. (*a*)	**16.** (*b*)	**17.** (*b*)	**18.** (*b*), (*d*)	**19.** (*c*), (*d*)	**20.** (*b*)	**21.** (*a*)
22. (*b*)	**23.** (*b*)	**24.** (*d*)				

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(a) *Both A and R are true and R is the correct explanation of A.*

(b) *Both A and R are true but R is not the correct explanation of A.*

(c) *A is true but R is false.*

(d) *A is false and R is also false.*

1. **Assertion (A) :** The nucleus ${}^{7}_{3}X$ is more stable than the nucleus ${}^{4}_{3}Y$.

   Reason (R) : ${}^{7}_{3}X$ contains more number of protons. *[CBSE 2023 (55/3/1)]*

2. **Assertion(A) :** Neutrons penetrate matter more readily as compared to proton.

   Reason (R) : Neutrons are slightly more massive than protons.

3. **Assertion(A) :** Energy is released in nuclear fission.

   Reason (R) : Total binding energy of fission fragments is larger than the total binding energy of the parent nucleus.

4. **Assertion(A) :** Forces acting between proton-proton (f_{pp}), proton-neutron (f_{pn}) and neutron-neutron (f_{nn}) are such that $f_{pp} < f_{pn} = f_{nn}$.

   Reason (R) : Electrostatic force of repulsion between two protons reduces net nuclear forces between them. *[AIIMS 2015]*

5. **Assertion(A) :** The elements produced in the fission are radioactive.

   Reason (R) : The fragments have abnormally high proton to neutron ratio.

6. **Assertion(A) :** The fusion process occurs at extremely high temperatures.

   Reason (R) : For fusion of two nuclei, enormously high kinetic energy is required.

7. **Assertion(A) :** A neutrino is chargeless and has a spin.

   Reason (R) : Neutrino exists inside the nucleus.

8. **Assertion(A) :** Mass is not conserved, but mass and energy are conserved as a single entity called mass-energy.

   Reason (R) : Mass and energy are inter-convertible in accordance with Einstein's relation, $E = mc^2$. *[AIIMS 2018]*

9. **Assertion(A) :** Thermonuclear fusion reactions may become the source of unlimited power for the mankind.

   Reason (R) : A single fusion event involving isotopes of hydrogen produces more energy than energy from nuclear fission of ${}^{235}_{93}\text{U}$. *[AIIMS 2017]*

10. **Assertion(A) :** The large angle scattering of α-particle is only due to nuclei.

    Reason (R) : Nucleus is very heavy as compared to electrons.

Answers

1. (*c*)	**2.** (*b*)	**3.** (*a*)	**4.** (*a*)	**5.** (*c*)	**6.** (*a*)	**7.** (*c*)
8. (*a*)	**9.** (*c*)	**10.** (*b*)				

Case-based/Passage-based Questions

Read the paragraph given below and answer the questions that follow:

Nuclear Holocaust: A nuclear holocaust, nuclear apocalypse or atomic holocaust is a theoretical scenario where the mass detonation of nuclear weapons causes globally widespread destruction and radioactive fall out. Under such scenario, large parts of the earth are made uninhabitable by nuclear warfare, potentially causing the collapse of civilization.

In a single uranium fission about 0.9×235 MeV (≈ 200 MeV) of energy is liberated. If each nucleus of about 50 kg of $^{235}U_{92}$ undergoes fission, the amount of energy involved is about 4×10^{15} J. This energy is equivalent to about 20,000 tons of TNT, enough for a super explosion. Uncontrolled release of large nuclear energy is called an atomic explosion.

(*i*) In a nuclear reactor, moderators slow down the neutrons which comes out in a fission process. The moderator used have light nuclei. Heavy nuclei will not serve the purpose because

(*a*) substance with heavy nuclei do not occur in liquid or gaseous state at room temperature

(*b*) the net weight of the reaction would be unbearably high

(*c*) elastic collision of neutrons with heavy nuclei will not slow down the neutrons

(*d*) they will break up

(*ii*) In an atomic bomb, the energy is released due to

(*a*) chain reaction of neutrons and U_{92}^{240}

(*b*) chain reaction of neutrons and U_{92}^{238}

(*c*) chain reaction of neutrons and U_{92}^{236}

(*d*) chain reaction of neutrons and U_{92}^{235}

(*iii*) Energy released in nuclear fission is due to

(*a*) total binding energy of fragments is more than the binding energy of parental element

(*b*) total binding energy of fragments is less than the binding energy of parental element

(*c*) total binding energy of fragments is equal to the binding energy of parental element

(*d*) some mass is converted into energy

(*iv*) Solar energy is mainly caused due to

(*a*) gravitational contraction

(*b*) fusion of proton during synthesis of heavier elements

(*c*) fission of uranium present in the sun

(*d*) burning of hydrogen in the oxygen

OR

Heavy stable nuclei have more neutrons than protons. This is because of the fact that

(*a*) electrostatic force between protons are repulsive

(*b*) neutrons decay into protons through beta decay

(*c*) nuclear forces between neutrons are weaker than that between protons

(*d*) neutrons are heavier than protons

Explanations

(*i*) (*c*) For elastic collision masses of both must be equal so that they can exchange the velocities. To slow down the speed of neutron, substance should be made up of 1 proton for perfectly elastic *i.e.*, we need light nuclei not heavy. In heavy nuclei only direction will change and not the speed.

(*ii*) (*d*) In an atomic bomb, the energy is released due to the chain reaction of neutrons and U_{92}^{235} nuclei.

(*iii*) (*a*) Energy released in nuclear fission is due to the fact that total binding energy of fragments is more than the binding energy of the parent nucleus.

(*iv*) (*b*) Solar energy is mainly caused due to the fusion of protons during the synthesis of heavier elements.

OR

(*a*) Electrostatic force between proton-proton is repulsive which cause the unstability of nucleus. So, more neutrons are needed to maintain the gap between protons and to stabilize the nucleus.

CONCEPTUAL QUESTIONS

Q. 1. Write two characteristic features of nuclear force which distinguish it from Coulomb's force. [*CBSE (AI) 2011*]

Ans. Characteristic Features of Nuclear Force:

(*i*) Nuclear forces are short range **attractive forces** (range 2 to 3 fm) while Coulomb's forces have range upto infinity and may be attractive or repulsive.

(*ii*) Nuclear forces are charge independent forces; while Coulomb's force acts only between charged particles.

Q. 2. The nuclear radius of $^{27}_{13}Al$ is 3.6 fermi. Find the nuclear radius of $^{64}_{29}Cu$. [*CBSE 2020 (55/1/1)*]

Ans. As we know, $R = R_0(A)^{\frac{1}{3}}$

$$\therefore \qquad \frac{R_2}{R_1} = \left(\frac{A_2}{A_1}\right)^{\frac{1}{3}} \Rightarrow \frac{R_2}{3.6} = \left(\frac{64}{27}\right)^{\frac{1}{3}}$$

$$\Rightarrow \quad R_2 = 3.6\left(\frac{64}{27}\right)^{\frac{1}{3}} = 3.6 \times \frac{4}{3} = \mathbf{4.8\ fermi}$$

Q. 3. Which one of the following cannot emit radiation and why?

Excited nucleus, excited electron [*NCERT Exemplar*]

Ans. Excited electron cannot emit radiation. This is because energy of electronic energy levels is in the range of eV only not in MeV and γ–radiation has energy in MeV.

Q. 4. In pair annihilation, an electron and a positron destroy each other to produce gamma radiation. How is the momentum conserved? [*NCERT Exemplar*]

Ans. 2γ-photons are produced which move in opposite directions to conserve momentum.

Q. 5. $^{3}_{2}He$ and $^{3}_{1}H$ nuclei have the same mass number. Do they have the same binding energy? [*NCERT Exemplar*] [*HOTS*]

Ans. No, the binding energy of $^{3}_{1}H$ is greater. This is because $^{3}_{2}He$ has 2 proton and 1 neutron, whereas $^{3}_{1}H$ has 1 proton and 2 neutron. Repulsive force between protons in $^{3}_{1}H$ is absent.

Q. 6. Four nuclei of an element undergo fusion to form a heavier nucleus, with release of energy. Which of the two — the parent or the daughter nucleus — would have higher binding energy per nucleon?

Ans. The daughter nucleus would have a higher binding energy per nucleon.

Q. 7. The mass of H-atom is less than the sum of the masses of a proton and electron. Why is this so? *[NCERT Exemplar] [HOTS]*

Ans. Einstein's mass-energy equivalence gives $E = mc^2$. Thus the mass of an H-atom is $m_p + m_e - \dfrac{B}{C^2}$ where $B \approx 13.6$ eV is the binding energy. It is less than the sum of masses of a proton and an electron.

Q. 8. Write two distinguishing features of nuclear forces. *[CBSE 2019 (55/3/1)]*

Ans. Nuclear force:

(*i*) The nuclear force is much stronger than coulomb's force.

(*ii*) The nuclear force between two nucleons falls rapidly to zero as their distance is more than few femto metres.

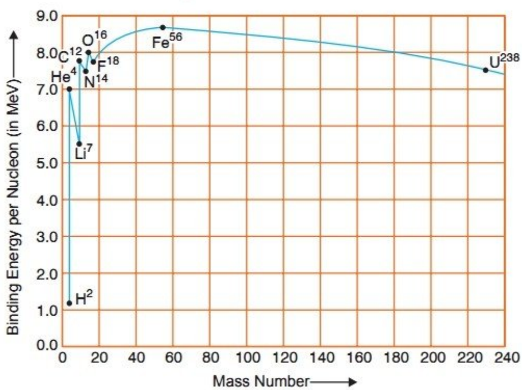
(*iii*) Nuclear force does not depend on the electric charge.

Very Short Answer Questions

Each of the following questions are of 2 marks.

Q. 1. Draw a graph showing the variation of binding energy per nucleon as a function of mass number A. The binding energy per nucleon for heavy nuclei ($A > 170$) decreases with the increase in mass number. Explain. *[CBSE 2023 (55/3/1)]*

Ans.



The binding energy per nucleon for heavy nuclei ($A > 170$) decreases with the increase in mass number because of more coulomb force of repulsion between protons of heavier nuclei. This results in less stability of heavier nuclei.

Q. 2. (*i*) What characteristic property of nuclear force explains the constancy of binding energy per nucleon (BE/A) in the range of mass number 'A' lying $30 < A < 170$?

(*ii*) Show that the density of nucleus over a wide range of nuclei is constant independent of mass number A. *[CBSE 2023 (55/2/1)]*

Ans. (*i*) Saturation or short range nature of nuclear forces.

(*ii*) The radius (size) R of nucleus sis related to its mass number (A) as

$R = R_0 A^{1/3}$, where $R_0 = 1.1 \times 10^{-15}$ m

If m is the average mass of a nucleon, then mass of nucleus = mA, where A is mass number

Volume of nucleus $= \frac{4}{3}\pi R^3 = \frac{4}{3}\pi (R_0 A^{1/3})^3 = \frac{4}{3}\pi R_0^3 A$

$\therefore$ Density of nucleus, $\rho_N = \frac{\text{mass}}{\text{volume}} = \frac{mA}{\frac{4}{3}\pi R_0^3 A} = \frac{m}{\frac{4}{3}\pi R_0^3} = \frac{3m}{4\pi R_0^3}$

Clearly nuclear density ρ_N is independent of mass number A.

Q. 3. Define the term, mass defect. How is it related to stability of the nucleus? [*CBSE 2023 (55/2/1)*]

Ans. The difference between mass of nucleus and the sum of the masses of its nucleons (*i.e.*, proton (p) and neutron (n)) is called its mass defect.

This mass defect is in the form of binding energy of nucleus, which is responsible for binding the nucleons in to a small nucleons. Hence, higher mass defect, higher is the stability of the nucleus.

Q. 4. Calculate the energy in fusion reaction: [*CBSE Delhi 2016*]

$${}^2_1H + {}^2_1H \longrightarrow {}^3_2He + n, \text{ where BE of } {}^2_1H = 2.23 \text{ MeV and of } {}^3_2He = 7.73 \text{ MeV}$$

Ans. Initial binding energy,

$BE_1 = (2.23 + 2.23)$

$= 4.46$ MeV

Final binding energy,

$BE_2 = 7.73$ MeV

$\therefore$ Energy released $= BE_2 - BE_1 = (7.73 - 4.46)$ MeV $=$ **3.27 MeV**

Q. 5. The electron in a hydrogen atom is typically found at a distance of about 5.3×10^{-11} m from the nucleus which has a diameter of about 1.0×10^{-15}m. Assuming the hydrogen atom to be a sphere of radius 5.3×10^{-11} m, what fraction of its volume is occupied by the nucleus?

[*CBSE 2022 (55/3/3), Term-2*]

Ans.

(b) Given radius of atom (r_a) = radius of electron orbit = 5.3×10^{-11} m

radius of nucleus (r_n) = $\frac{\text{diameter}}{2} = \frac{1.0 \times 10^{-15}}{2}$ m $= 5 \times 10^{-16}$ m

Volume of atom $= \frac{4}{3}\pi r_a^3$

Volume of nucleus $= \frac{4}{3}\pi r_n^3$

$\Rightarrow$ Fraction of its volume occupied by the nucleus $= \frac{(\text{Volume})_{\text{nucleus}}}{(\text{Volume})_{\text{atom}}} = \frac{\cancel{\frac{4}{3}\pi} r_n^3}{\cancel{\frac{4}{3}\pi} r_a^3}$

$= \left(\frac{r_n}{r_a}\right)^3$

$= \left(\frac{5}{5.3} \times 10^{-5}\right)^3$

$= \frac{125}{5.3 \times 5.3 \times 5.3} \times 10^{-15}$

Ans: Thus, fraction of ~~value~~ volume of hydrogen atom occupied by its nucleus

$$= \boxed{8.395 \times 10^{-16}}$$

140450
148877
8.395
1489) 12500
11912
5880
4467
14130
13401
7290

1489 × 8 = 11912
1489 × 9 = 13401
1489 × 5 = 7445

[*Topper's Answer 2022*]

Q. 6. **(*i*) Distinguish between isotopes and isobars.**

(*ii*) Two nuclei have different mass numbers A_1 and A_2. Are these nuclei necessarily the isobars of the same element? Explain. [*CBSE 2022 (55/3/1), (55/3/3), Term-2*]

Ans. 1.

(a)

(i)

ISOTOPES	ISOBARS
→ The atoms which have the same atomic number but different mass number are isotopes (atoms of ~~same elements~~)	→ The atoms which have different atomic number but same mass number are isobars (atoms of different elements)
→ Isotopes have same number of protons in them	→ Isobars have different number of protons in them
→ Their (p+n) no. is not constant	→ Their (p+n) number is constant.
→ Eg: H_1^1, H_1^2, H_1^3	→ Eg: Ar_{18}^{40}, Ca_{18}^{40}

(ii) Isotopes have same atomic number but different mass number. In other words isotopes have equal number of protons but only differ in number of neutrons

Given two nuclei ~~A_1 and A_2~~ have different mass numbers A_1 and A_2. These two nuclei can be isotope only if they have the same atomic number.

For eg: He_2^4 and H_1^2 have different mass number but they are not isotopes

H_1^1 and H_1^2 also have different mass number but they are isotopes

Ans: Thus, if two nuclei have different mass numbers A_1 and A_2 they cannot necessarily be isotopes of the same element.

[*Topper's Answer 2022*]

Q. 7. A given coin has a mass of 3.0 g. Calculate the nuclear energy that would be required to separate all the neutrons and protons from each other. For simplicity assume that the coin is entirely made of ${}^{63}_{29}Cu$ atoms (of mass 62.92960 u). The masses of proton and neutrons are 1.00783 u and 1.00867 u respectively. **[*NCERT*]**

Ans. Masses of protons and neutrons in 63 u of Cu

$$= Zm_p + (A-Z)m_n = 29m_p + (63-29)m_n$$

$$= 29 \times 1.00783 + (34 \times 1.00867) = 29.22707 + 34.29478 = 63.52185 \text{ u}$$

Mass of ${}^{63}_{29}Cu$ atom = 62.92960 u

Mass defect = 63.52185 – 62.92960 = 0.59225 u

Energy released in ${}^{63}_{29}Cu$ atom = 0.59225 × 931 MeV = 551.385 MeV

Number of atoms in 3 g of copper $= \dfrac{6.02 \times 10^{23}}{63} \times 3 = 2.87 \times 10^{22}$

$\therefore$ Energy required to separate all nucleons (neutrons and protons) from each other

$$= 2.87 \times 10^{22} \times 551.385 \text{ MeV} = \mathbf{1.6 \times 10^{25}\ MeV}$$

Q. 8. Why do stable nuclei never have more protons than neutrons? **[*NCERT Exemplar*] [*HOTS*]**

Ans. Protons are positively charged and repel one another electrically. This repulsion becomes so great in nuclei with more than 10 protons or so, that an excess of neutrons which produce only attractive forces, is required for stability.

Q. 6. A nuclide 1 is said to be the mirror isobar of nuclide 2 if $Z_1 = N_2$ and $Z_2 = N_1$.

(*a*) What nuclide is a mirror isobar of ${}^{23}_{11}Na$?

(*b*) Which nuclide out of the two mirror isobars has greater binding energy and why?

[*NCERT Exemplar*] [*HOTS*]

Ans. (*a*) ${}^{23}_{11}Na : Z_1 = 11, N_1 = 12$

$\therefore$ Mirror isobar of ${}^{23}_{11}Na = {}^{23}_{12}Mg$.

(*b*) Since $Z_2 > Z_1$, Mg has greater binding energy than Na.

Q. 5. Two nuclei may have the same radius, even though they contain different number of protons and neutrons. Explain. **[*CBSE 2022 (55/3/3), Term-2*]**

Ans.

(b) Radius of a nuclei is given by

$$\boxed{R = R_0 A^{1/3}}$$

where $R_0 = 1.2 \times 10^{-15}$ m

A = mass ~~no~~ number of the nucleus
= No ~~of~~ nucleons in the nucleus (n+p)

Let two nuclei are there A and B,
A has n_1 ~~Autrons~~ neutrons and p_1 protons
B has n_2 neutrons and p_2 protons

Such that $n_2 \neq n_1$ and $p_2 \neq p_1$,

$$n_1 + p_1 = n_2 + p_2$$

Mass number of A = Mass number of B

but if two nuclei have same mass numbers they would have equal ~~same~~ radius

$$\boxed{R_A = R_B}$$

Ans. Hence two nuclei having different number of protons and neutrons may have the same radius: [Equality holds] If the sum of the number of proton and neutrons in both of them are same

[*Topper's Answer 2022*]

Short Answer Questions

Each of the following questions are of 3 marks.

Q. 1. In a typical nuclear reaction, *e.g.*,

$${}^2_1\text{H} + {}^2_1\text{H} \longrightarrow {}^3_2\text{He} + \text{n} + 3.27 \text{ MeV},$$

although number of nucleons is conserved, yet energy is released. How? Explain.

[*CBSE Delhi 2013*]

Ans. In nuclear reaction

$${}^2_1\text{H} + {}^2_1\text{H} \longrightarrow {}^3_2\text{He} + \text{n} + 3.27\,\text{MeV}$$

Cause of the energy released:

(*i*) Binding energy per nucleon of ${}^3_2\text{He}$ becomes more than the (BE/A) of ${}^2_1\text{H}$.

(*ii*) Mass defect between the reactant and product nuclei

$$\Delta E = \Delta m\, c^2 = [2m({}^2_1\text{H}) - m({}^3_2\text{He}) + m(\text{n})]c^2$$

Q. 2. (*a*) In the following nuclear reaction

$$\text{n} + {}^{235}_{92}\text{U} \longrightarrow {}^{144}_{Z}\text{Ba} + {}^{A}_{36}\text{X} + 3\text{n},$$

assign the values of *Z* and *A*.

(*b*) If both the number of protons and the number of neutrons are conserved in each nuclear reaction, in what way is the mass converted into energy? Explain. [*CBSE Guwahati 2015*]

Ans. (*a*) $\text{n} + {}^{235}_{92}\text{U} \longrightarrow {}^{144}_{Z}\text{Ba} + {}^{A}_{36}\text{X} + 3\text{n}$,

From law of conservation of atomic number

$$0 + 92 = Z + 36$$

$$\Rightarrow \quad Z = 92 - 36 = \mathbf{56}$$

From law of conservation of mass number,

$$1 + 235 = 144 + A + 3 \times 1$$

$$A = 236 - 147 = \mathbf{89}$$

(*b*) (*i*) *BE* of $^{235}_{92}U$ < *BE* of $(^{144}_{56}Ba + ^{89}_{36}X)$ and due to difference in *BE* of the nuclides. A large amount of the energy will released in the fission of $^{235}_{92}U$.

(*ii*) Mass number of the reactant and product nuclides are same but there is an actual mass defect. This difference in the total mass of the nuclei on both sides, gets converted into energy, *i.e.*, $\Delta E = \Delta mc^2$.

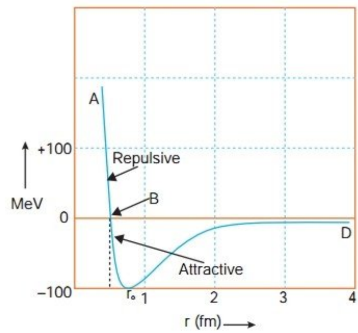
Q. 3. Draw a graph showing the variation of potential energy between a pair of nucleons as a function of their separation. Indicate the regions in which the nuclear force is (*i*) attractive, (*ii*) repulsive.

Write two important conclusions which you can draw regarding the nature of the nuclear forces. ***[CBSE 2019 (55/4/2), 2020 (55/3/1)]***

Ans. Conclusions:

(*i*) The potential energy is minimum at a distance r_0 of about 0.8 fm.

(*ii*) Nuclear force is attractive for distance larger than r_0.



(*iii*) Nuclear force is repulsive if two are separated by distance less than r_0.

(*iv*) Nuclear force decreases very rapidly at r_0/equilibrium position.

Q. 4. The Q-value of a nuclear reaction

$$\mathbf{A + B \longrightarrow C + D}$$

is defined by $Q = (m_A + m_B - m_C - m_D)\,c^2$

where the masses refer to the nuclear rest masses. Determine from the given data whether the following reactions are exothermic or endothermic.

(*i*) $^1_1H + ^3_1H \rightarrow ^2_1H + ^2_1H$ (*ii*) $^{12}_6C + ^{12}_6C \rightarrow ^{20}_{10}Ne + ^4_2He$

Atomic masses are given to be:

$m(^1_1H) = 1.007825$ u $m(^2_1H) = 2.014102$ u

$m(^3_1H) = 3.016049$ u $m(^{12}_6C) = 12.00000$ u

$m(^{20}_{10}Ne) = 19.992439$ u $m(^4_2He) = 4.002603$ u

Take 1 u = 931 MeV ***[NCERT]***

Ans. (*i*) Nuclear reaction is

$$^1_1H + ^3_1H \rightarrow ^2_1H + ^2_1H + Q$$

Mass of LHS = $m(^1_1H) + m(^3_1H) = 1.007825 + 3.016049 = 4.023874$ u

Mass of RHS = $m(^2_1H) + m(^2_1H) = 2.014102 + 2.014102 = 4.028204$ u

$$Q = [(m_A + m_B - m_C - m_D) \text{ in kg}] \times c^2 \text{ joule}$$
$$= [(m_A + m_B - m_C - m_D)\text{u}] \times 931 \text{ MeV}$$
$$= \left[\{m({}^1_1\text{H}) + m({}^3_1\text{H})\} - \{m({}^2_1\text{H}) + m({}^2_1\text{H})\}\right] \times 931 \text{ MeV}$$
$$= [4.023874 - 4.028204] \times 931 \text{ MeV}$$
$$= -0.00433 \times 931 \text{ MeV} = \mathbf{-4.031 \text{ MeV}}$$

As Q is negative, energy must be supplied for the reaction; hence the reaction is **endothermic**.

(*ii*) Nuclear reaction: ${}^{12}_{6}\text{C} + {}^{12}_{6}\text{C} = {}^{20}_{10}\text{Ne} + {}^{4}_{2}\text{He}$

$$Q = [\{m({}^{12}_{6}\text{C}) + m({}^{12}_{6}\text{C})\} - \{m({}^{20}_{10}\text{Ne}) + m({}^{4}_{2}\text{He})\}] \times c^2 \text{ joule}$$
$$= [(12.000000 + 12.000000) - (19.992439 + 4.002603)] \times c^2 \text{ joule}$$
$$= (24.000000 - 23.995042) \times 931 \text{ MeV} = 0.004958 \times 931 \text{ MeV} = \mathbf{4.616 \text{ MeV}}$$

As Q is positive, the energy will be liberated in the reaction, hence the reaction is **exothermic**.

Q. 5. (*i*) Distinguish between nuclear fission and fusion giving an example of each.

(*ii*) Explain the release of energy in nuclear fission and fusion on the basis of binding energy per nucleon curve. **[*CBSE 2023 (55/2/1)*]**

Ans. (*i*) **Nuclear fission:** It is a process in which a heavy nucleus when excited (say on bombarding by a slow moving neutron) splits into two lighter nuclei of nearly comparable masses with a release of large amount of energy.

Example of nuclear fission

$${}^1_0n + {}^{235}_{92}U \longrightarrow {}^{236}_{92}U \longrightarrow {}^{144}_{56}Ba + {}^{89}_{36}Kr + 3\,{}^1_0n + Q$$

Nuclear fusion: It is a process in which two lighter nuclei fuse (at extremely high temperature) to form a heavy nucleus and large amount of energy is released.

Example of nuclear fusion

(1) ${}^1_1H + {}^1_1H \longrightarrow {}^2_1H + e^+ + \nu + Q_1$

(2) ${}^2_1H + {}^2_1H \longrightarrow {}^3_2H_e + n + Q_2$

(3) ${}^2_1H + {}^2_1H \longrightarrow {}^3_1H + {}^1_1H + Q_3$

(*ii*) The binding energy per nucleon of the products in the nuclear reactions (nuclear fission and nuclear fusion) is greater than that of the reactants.

Long Answer Questions

Each of the following questions are of 5 marks.

Q. 1. Draw the graph showing the variation of binding energy per nucleon with the mass number for a large number of nuclei $2 < A < 240$. What are the main inferences from the graph? How do you explain the constancy of binding energy in the range $30 < A < 170$ using the property that the nuclear force is short-ranged? Explain with the help of this plot the release of energy in the processes of nuclear fission and fusion.

[*CBSE (AI) 2010, 2011, Chennai 2015, South 2016, 2020 (55/5/2)*]

OR

Draw a diagram to show the variation of binding energy per nucleon with mass number for different nuclei and mention its two features. Why do lighter nuclei usually undergo nuclear fusion? **[*CBSE 2023 (55/2/1)*]**

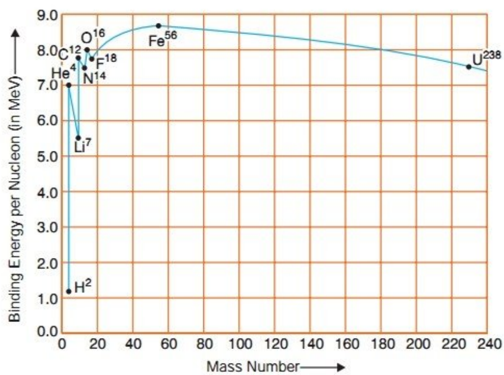
Ans. The variation of binding energy per nucleon versus mass number is shown in figure.

Inferences from graph

1. The nuclei having mass number below 20 and above 180 have relatively small binding energy and hence they are unstable.
2. The nuclei having mass number 56 and about 56 have maximum binding energy – 8·8 MeV and so they are most stable.
3. Some nuclei have peaks, *e.g.*, ${}^{4}_{2}He, {}^{12}_{6}C, {}^{12}_{6}O$; this indicates that these nuclei are relatively more stable than their neighbours.

(*i*) **Explanation of constancy of binding energy:** Nuclear force is short ranged, so every nucleon interacts with its neighbours only, therefore binding energy per nucleon remains constant.

(*ii*) **Explanation of nuclear fission:** When a heavy nucleus ($A \geq 235$ say) breaks into two lighter nuclei (nuclear fission), the binding energy per nucleon increases *i.e*, nucleons get more tightly bound. This implies that energy would be released in nuclear fission.



(*iii*) **Explanation of nuclear fusion:** When two very light nuclei ($A \leq 10$) join to form a heavy nucleus, the binding is energy per nucleon of fused heavier nucleus more than the binding energy per nucleon of lighter nuclei, so again energy would be released in nuclear fusion.

Q. 2. (*i*) **Define the following terms:**

(*a*) **Nucleons,** (*b*) **Atomic number,** (*c*) **Mass number,** (*d*) **Nuclear mass**

(*ii*) **What are** (*a*) **isotopes,** (*b*) **isobars and** (*c*) **isotones?**

Ans. (*i*) (*a*) **Nucleons:** The constituents of nucleus *i.e.*, protons and neutrons are considered as nucleons.

(*b*) **Atomic number:** The number of protons present in the nucleus is called the atomic number of the element. It is denoted by Z.

(*c*) **Mass number:** The total number of nucleons *i.e.*, sum of protons and neutrons present in a nucleus is called the mass number of the element. It is denoted by A.

(*d*) **Nuclear mass:** The total mass of protons and neutrons present in a nucleus is called the nuclear mass.

(*ii*) (*a*) **Isotopes:** The atoms of an element having same atomic number (Z) but different mass numbers (A) are called isotopes.

(*b*) **Isobars:** The elements having same mass number (A) and different atomic number (Z) are called isobars.

(*c*) **Isotones:** The nuclei containing the same number of neutrons are called isotones.

Q. 3. (*i*) What is nuclear fission? Give one representative equation.

(*ii*) (*a*) What is nuclear fusion? Give one representative equation.

(*b*) State the necessary conditions for nuclear fusion to occur.

Ans. (*i*) **Nuclear fission:** The phenomenon in which a heavy nucleus (A > 230) when excited splits into two smaller nuclei of nearly comparable masses is called nuclear fission. For example, when a uranium target is bombarded by slow moving neutrons, a $^{235}_{92}\text{U}$ nucleus gets excited by capturing a slow moving neutron and splits into two nearly equal fragments like $^{141}_{56}\text{Ba}$ and $^{92}_{36}\text{Kr}$ alongwith the emission of 3 neutrons. The nuclear reaction involved can be written as

$$^{235}_{92}\text{U} + ^{1}_{0}n \longrightarrow ^{236}_{92}\text{U} \longrightarrow ^{141}_{56}\text{Ba} + ^{92}_{36}\text{Kr} + 3\,^{1}_{0}n + Q$$

Fission does not always produce barium and krypton. A number of other pairs are formed.

For example,

$$^{235}_{92}\text{U} + ^{1}_{0}n \longrightarrow ^{236}_{92}\text{U} \longrightarrow ^{133}_{51}\text{Sb} + ^{99}_{41}\text{Nb} + 3\,^{1}_{0}n + Q$$

$$^{235}_{92}\text{U} + ^{1}_{0}n \longrightarrow ^{236}_{92}\text{U} \longrightarrow ^{140}_{54}\text{Xe} + ^{94}_{38}\text{Sr} + 2\,^{1}_{0}n + Q$$

(*ii*) (*a*) The phenomenon of combination of two or more light nuclei to form a heavy nucleus with release of enormous amount of energy is called the nuclear fusion.

For example, the fusion of two deuterons into a triton takes place as follows:

$$_1\text{H}^2 + _1\text{H}^2 \longrightarrow _1\text{H}^3 + ^1_1\text{H} + 4.0\text{ MeV energy}$$

Alternatively the fusion of three deuterons into an $\alpha-$ particle can take place as follows:

$$_1\text{H}^2 + _1\text{H}^2 \longrightarrow _2\text{He}^3 + _0\text{n}^1 + 3.3\text{ MeV energy}$$

$$_2He^2 + _1\text{H}^2 \longrightarrow _2\text{He}^4 + _1H^1 + 18.3\text{ MeV energy}$$

(*b*) The necessary conditions for nuclear fusion are:

High temperature: The high temperature is necessary for the light nuclei to have sufficient kinetic energy so that they can overcome the repulsion force between them.

High density: High density or pressure increases the frequency of collision of light nuclei and hence increases the rate of fusion.

Questions for Practice

1. Choose and write the correct option in the following questions.

(*i*) How does the binding energy per nucleon vary with the increase in the number of nucleons

(*a*) decrease continuously with mass number

(*b*) first decreases and then increases with increase in mass number

(*c*) first increases and then decreases with increase in mass number

(*d*) increases continuously with mass number

(*ii*) Two spherical nuclei have mass numbers 216 and 64 with their radii R_1 and R_2 respectively. The ratio, $\frac{R_1}{R_2}$ is equal to

(*a*) 3 : 2 (*b*) 1 : 3

(*c*) 1 : 2 (*d*) 2 : 3

(*iii*) If number of nucleons in nuclei increases, the binding energy per nucleon

(*a*) increases

(*b*) decreases

(*c*) first increases and then decreases

(*d*) remains unchanged

(*iv*) A nucleus disintegrates into two nuclear parts, which have their velocities in the ratio 2 : 1. The ratio of their nuclear sizes will be

(*a*) $2^{1/3} : 1$ (*b*) $1 : 3^{1/2}$

(*c*) $3^{1/2} : 1$ (*d*) $1 : 2^{1/3}$

(*v*) The difference in mass ^7X nucleus and total mass of its constituent nucleons is 21.00 u. The binding energy per nucleon for this nucleus is equal to the energy equivalent of **[*CBSE 2023 (55/4/1)*]**

(*a*) 3 u (*b*) 3.5 u

(*c*) 7 u (*d*) 21 u

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

(a) ***Both A and R are true and R is the correct explanation of A.***

(b) ***Both A and R are true but R is not the correct explanation of A.***

(c) ***A is true but R is false.***

(d) ***A is false and R is also false.***

Assertion (*A*) **:** Density of all nuclei is same.

Reason (*R*) **:** The radius of nucleus is directly proportional to the cube root of mass number.

3. A nucleus with mass number $A = 240$ and $BE/A = 7.6$ MeV breaks into two fragments each of $A = 120$ with $BE/A = 8.5$ MeV. Calculate the released energy.

4. Two nuclei have mass numbers in the ratio 2 : 5. What is the ratio of their nuclear densities?

5. What is the nuclear radius of ^{125}I, if that of ^{27}Al is 3.6 fermi? **[*CBSE (AI) 2008*]**

6. Write the relationship between the size of a nucleus and its mass number (A). **[*CBSE (F) 2012*]**

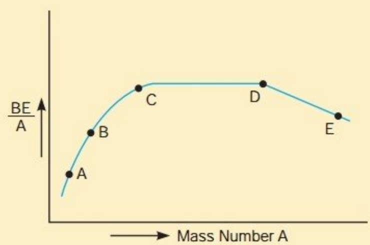
7. Two nuclei have mass numbers in the ratio 1 : 2. What is the ratio of their nuclei densities? **[*CBSE Delhi 2009*]**

8. Two nuclei have mass numbers in the ratio 1 : 8. What is the ratio of their nuclear radii? **[*CBSE (AI) 2009*]**

9. A heavy nucleus X of mass number 240 and binding energy per nucleon 7.6 MeV is split into two fragments Y and Z of mass numbers 110 and 130. The binding energy per nucleon in Y and Z is 8.5 MeV per nucleon. Calculate the energy Q released per fission in MeV. **[*CBSE Delhi 2010*]**

10. A heavy nucleus P of mass number 240 and binding energy 7.6 MeV per nucleon splits into two nuclei Q and R of mass number 110, 130 and binding energy per nucleon 8.5 MeV and 8.4 MeV respectively. Calculate the energy released in the fission. **[*CBSE 2020 (55/5/1)*]**

11. The figure shows the plot of binding energy (BE) per nucleon as a function of mass number A. The letters A, B, C, D and E represent the positions of typical nuclei on the curve. Point out, giving reasons, the two processes (in terms of A, B, C, D and E), one of which can occur due to nuclear fission and the other due to nuclear fusion.



12. Calculate for how long will the fusion of 2.0 kg deuterium keep 800 W electric lamp glowing. Take the fusion reaction as **[*CBSE 2020 (55/5/3)*]**

$$^{2}_{1}\mathrm{H} + ^{2}_{1}\mathrm{H} \longrightarrow ^{3}_{2}\mathrm{He} + ^{1}_{0}\mathrm{n} + 3.27\ \mathrm{MeV}$$

13. (*a*) The density of the nuclear matter is tremendously larger than the physical density of the material. Explain.

    (*b*) The nuclear forces are not coulomb forces between nucleons. Explain.

    (*c*) Draw a plot of the potential energy between a pair of nucleons as a functions distance between them inside a nucleus. **[*CBSE 2020 (55/3/1)*]**

14. When four hydrogen nuclei combine to form a helium nucleus, estimate the amount of energy in MeV released in this process of fusion. (Neglect the masses of electrons and neutrinos) Given:

    (*i*) mass of $^{1}_{1}\mathrm{H} = 1.007825$ u

    (*ii*) mass of helium nucleus = 4.002603 u, 1 u = 931 MeV/c^2 **[*CBSE (F) 2011*]**

15. (*a*) Distinguish between isotopes and isobars, giving one example for each.

(*b*) Why is the mass of a nucleus always less than the sum of the masses of its constituents? Write one example to justify your answer. **[*CBSE 2019 (55/5/1)*]**

16. (*a*) Classify the following six nuclides into

(*i*) isotones, (*ii*) isotopes, and (*iii*) isobars:

$$^{12}_{6}C, ^{3}_{2}He, ^{198}_{80}Hg, ^{3}_{1}H, ^{197}_{79}Au, ^{14}_{6}C$$

(*b*) How does the size of a nucleus depend on its mass number? Hence explain why the density of nuclear matter should be independent of the size of the nucleus. **[*CBSE 2019 [55/5/1)*]**

17. (*a*) (*i*) Depict the variation of the potential energy of a pair of nucleons with the separation between them.

(*ii*) Imagine the fission of a $^{56}_{26}Fe$ into two equal fragments of $^{28}_{13}Al$ nucleus. Is the fission energetically possible ? Justify your answer by working out Q value of the process.

Given: $m\left(^{56}_{26}Fe\right) = 55{\cdot}93494$ u, $m\left(^{28}_{13}Al\right) = 27{\cdot}98191$u. **[*CBSE 2022 (55/2/1), Term-2*]**

18. Distinguish between nuclear fission and fusion. Show how in both these processes energy is released.

Calculate the energy release in MeV in the deuterium-tritium fusion reaction:

$$^{2}_{1}H + ^{3}_{1}H \longrightarrow ^{3}_{2}He + n$$

Using the data:

$m(^{2}_{1}H) = 2.014102$ u $\quad m(^{3}_{1}H) = 3.016049$ u $\quad m(^{3}_{2}He) = 4.002603$ u

$m_n = 1.008665$ u $\quad 1u = 931.5\ MeV/c^2$

19. Draw the curve showing the variation of binding energy per nucleon with the mass number of nuclei. Using it explain the fusion of nuclei lying on ascending part and fission of nuclei lying on descending part of this curve. **[*CBSE 2020 (55/5/2)*]**

20. (*a*) In a typical nuclear reaction, *e.g.*,

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{2}He + n + 3.27\ MeV,$$

although number of nucleons is conserved, yet energy is released. How? Explain.

(*b*) Show that nuclear density in a given nucleus is independent of mass number A.

21. Obtain the binding energy of the nuclei $^{56}_{26}Fe$ and $^{209}_{83}Bi$ in units of MeV from the following data. $m_H = 1.007825$ u, $m_n = 1.008665$ u, $m(^{56}_{26}Fe) = 55.934939$ u, $m(^{209}_{83}Bi) = 208.980388$ u, 1 u = 931.5 MeV. Which nucleus has greater binding energy per nucleon? **[*NCERT*]**

22. How long an electric lamp of 100 W can be kept glowing by fusion of 2.0 kg of deuterium? The fusion reaction can be taken as: **[*NCERT*] [*HOTS*]**

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{2}He + n + 3.2\ MeV$$

Answers

1. (*i*) (*c*) (*ii*) (*a*) (*iii*) (*c*) (*iv*) (*d*) (*v*) (*a*)
2. (*a*)
3. 216 MeV
4. 1 : 1
5. 6 fermi
8. 1 : 2
9. 216 MeV
10. 203 MeV
12. 1.96×10^{11} s
14. 26.72 MeV
18. 17.59 MeV
21. 8.79 MeV/nueleon, 7.848 MeV/nueleon
22. 4.9×10^4 years

14 Electronic Devices

POINTS TO REMEMBER

1. Electronics

A device whose functioning is based on controlled movement of electrons through it is called an electronic device. Some of the present-day most common such devices include a semiconductor junction diode, a transistor and integrated circuits. The related branch in which we study the functioning and use of such devices is called Electronics.

2. Energy Bands in Solids

An isolated atom has well defined energy levels. However, when large number of such atoms get together to form a real solid, these individual energy levels overlap and get completely modified. Instead of discrete value of energy of electrons, the energy values lie in a certain range. The collection of these closely packed energy levels are said to form an energy band. Two types of such bands formed in solids are called Valence Band and Conduction Band. The band formed by filled energy levels is known as Valence Band whereas partially filled or unfilled band is known as Conduction Band. The two bands are generally separated by a gap called energy gap or forbidden gap. Depending upon the size of this energy gap, different materials behave as conductors, semi-conductors or insulators. The insulators have generally large energy gap whereas the conductors do not have any such gap. Semi-conductors have small energy gap.

3. Types of Semi-conductors—Intrinsic and Extrinsic

Common Semiconductors are of two types—intrinsic and extrinsic. Germanium and silicon are two most commonly used semiconductor material.

Intrinsic Semiconductor: Pure semiconductors is in which the conductivity is caused due to charge carriers made available from within the material are called *intrinsic semiconductors*. There are no free charge carriers available under normal conditions. However, when the temperature is raised slightly, some of the covalent bonds in the material get broken due to thermal agitation and few electrons become free. In order to fill the vacancy created by absence of electron at a particular location, electron from other position move to this location and create a vacancy (absence of electron) at another place called *hole*. The movement/shifting of electrons and holes within the material results in conduction.

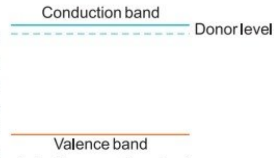
An intrinsic semiconductors behaves as a perfect insulator at temperature 0 K.

Extrinsic semiconductors: The semiconductors in which the conductivity is caused due to charge carriers made available from external source by adding impurity from outside are called *extrinsic semiconductor*. The process of adding impurity is called *doping*. The impurity added is generally from third group or fifth group. There are two types of extrinsic semiconductors:

(*a*) n–Type or (*b*) p–Type.

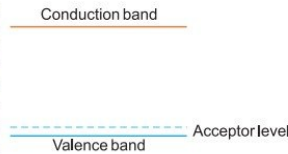
If n_i is the density of intrinsic charge carriers, n_e and n_h are densities of electrons and hole in extrinsic semiconductors, then the selection among them is $n_e n_h = n_i^2$

(*a*) **n-type semiconductors:** When a pentavalent impurity like Phosphorus, Antimony, Arsenic is doped in pure-Germanium (or Silicon), then the conductivity of crystal increases due to surplus electrons and such a crystal is said to be n-type semiconductor, while the impurity atoms are called **donors atoms**. Thus, in n-type semiconductors the charge carriers are negatively charged electrons and the donor level lies near the bottom of the conduction band.



(*a*) ***n*-type semiconductor**

(*b*) **p-type semiconductors:** When a trivalent impurity like Aluminium, Indium, Boron, Gallium, etc., is doped in pure Germanium (or silicon), then the conductivity of the crystal increases due to deficiency of electrons *i.e.*, holes and such a crystal is said to be p–type semiconductor while the impurity atoms are called **acceptors**. Thus in p–type semiconductors the charge carriers are holes. Acceptor level lies near the top of the valence band.



(*b*) ***p*-type semiconductor**

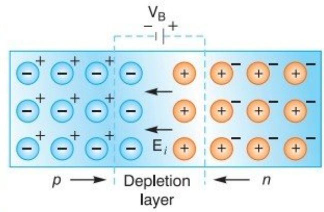
4. Semiconductor Diode: *p-n* Junction Diode

A semiconductor having p-type impurity at one end and n-type impurity at the other end is known as $p - n$ junction diode. The junction at which p-type and n-type semiconductors combine is called p-n junction.

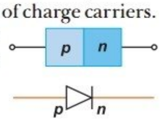
In p-type region there is majority of holes and in n-type region there is majority of electrons.

Formation of Depletion Layer and Potential Barrier

At the junction, there is diffusion of charge carriers due to thermal agitation; therefore some of electrons of n-region diffuse to p-region while some of holes of p-region diffuse into n-region. Some charge carriers combine with opposite charges to neutralise each other. Thus, near the junction there is an excess of positively charged ions in n-region and an excess of negatively charged ions in p-region. This sets up a potential difference called **potential barrier** and hence an internal electric field E_i across the junction. The potential barrier is usually of the order of µV. The field E_i is directed from n-region to p-region. This field stops the further diffusion of charge carriers.



Thus the layers (≈10^{-4} cm to 10^{-6} cm) on either side of the junction becomes free from mobile charge carriers and hence is called the *depletion layer.* The symbol of p-n junction diode is shown in figure.



Forward and Reverse Bias

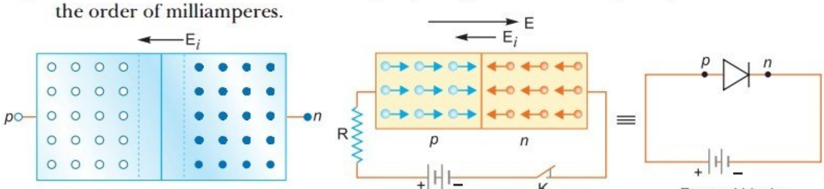
The external battery is connected across the junction in the following two ways:

(*i*) **Forward Bias:** In this arrangement the positive terminal of battery is connected to p-end and negative terminal to n-end of the crystal, so that an external electric field E is established directed from p to n-end to oppose the internal field E_i. Thus, the junction is said to conduct.

Under this arrangement the holes move along the field E from p-region to n-region and electrons move opposite to field E from n-region to p-region; eliminating the depletion layer. A current is thus set up in the junction diode. The following are the basic features of forward biasing:

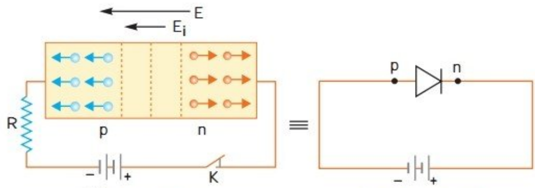
(*a*) Within the junction diode the current is due to both types of majority charge carriers but in external circuit it is due to electrons only.

(*b*) The current is due to diffusion of majority charge carriers through the junction and is of the order of milliamperes.



(*a*) No current (*b*) Forward current Forward biasing

(*ii*) Reverse Bias: In this arrangement the positive terminal of battery is connected to *n*-end and negative terminal to *p*-end of the crystal, so that the external field is established to support the internal field E_i as shown in fig. Under the biasing the holes in *p*-region and the electrons in *n*-region are pushed away from the junction to widen the depletion layer and hence increases the size of the potential barrier, therefore, the junction does not conduct.



(c) Reverse current Reverse biasing

When the potential difference across the junction is increased in steps, a very small reverse current of the order to micro-amperes flows. The reason is that due to thermal agitation some covalent bonds of pure semi-conductor break releasing a few holes in *n*-region and a few electrons in *p*-region called the *minority charge carriers*. The reverse bias opposes the majority charge carriers but aids the minority charge carriers to move across the junction. Hence a very small current flows.

The basic features of reverse bias are:

(*a*) Within the junction diode the current is due to both types of minority charge carriers but in external circuit it is due to electrons only.

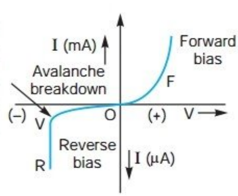
(*b*) The current is due to leakage of minority charge carriers through the junction and is very small of the order of μA.

Characteristics of a *p–n* junction diode:

The graph of voltage *V* versus current *I* in forward bias and reverse bias of a *p–n* junction is shown in the figure.

Avalanche Break Down:

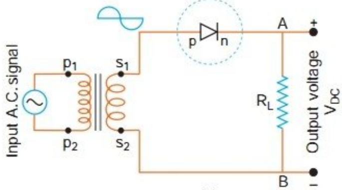
If the reverse bias is made sufficiently high, the covalent bonds near the junction break down releasing free electrons and holes. These electrons and holes gain sufficient energy to break other covalent bonds. Thus a large number of electrons and holes get free. The reverse current increases abruptly to high value. This is called avalanche break down and may damage the junction.



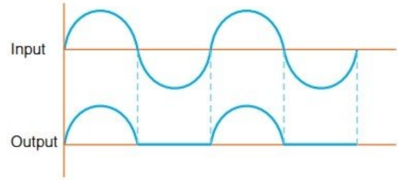
5. *p-n* Junction Diode as a Half-wave Rectifier

The conversion of ac into dc is called the rectification.

Half Wave Rectifier: The circuit diagram for junction diode as half wave rectifier is shown in fig. (*a*)



(a)

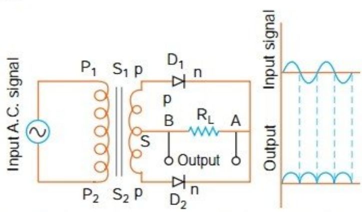


(b)

During first half of the input cycle, the secondary terminal S_1 of transformer be positive relative to S_2 then the junction diode is forward biased. Therefore, the current flows and its direction of current in load resistance R_L is from A to B. In next half cycle, the terminal S_1 becomes negative relative to S_2, then the diode is in reverse bias, therefore no current flows in diode and hence there is no potential difference across load R_L. The cycle repeats. The output current in load flows only when S_1 is positive relative to S_2 That is during first half cycles of input ac signal there is a current in circuit and hence a potential difference across load resistance R_L while no current flows, for next half cycle. The direction of current in load is always from A to B which is direct current. Thus, a *single p-n junction diode acts as a half wave rectifier*.

The input and output waveforms of half wave rectifier are shown in fig. (*b*).

Full Wave Rectifier: For full wave rectifier, we use two junction diodes. The circuit diagram for full wave rectifier using two junction diodes is shown in figure.



During first half cycle of input ac signal the terminal S_1 is positive relative to S and S_2 is negative relative to S, then diode D_1 is forward biased and diode D_2 is reverse biased. Therefore current flows in diode D_1 and not in diode D_2. The direction of current i_1 due to diode D_1 in load resistance R_L is directed from A to B. In next half cycle, the terminal S_1 is negative relative to S and S_2 is positive relative to S. Then diode D_1 is reverse biased and diode D_2 is forward biased. Therefore, current flows in diode D_2 and there is no current in diode D_1. The direction of current i_2 due to diode D_2 in load resistance is again from A to B Thus, for input ac signal the output current is a continuous series of unidirectional pulses. The input and output sequels are shown in the figure. This output current can be converted into steady current by the use of suitable filters.

Remark: In full wave rectifier if the fundamental frequency of input ac signal is 50 Hz, then the fundamental frequency of output is 100 Hz.

Multiple Choice Questions

Choose and write the correct option(s) in the following questions.

1. **When an intrinsic semiconductor is doped with a small amount of trivalent impurity, then** *[CBSE 2023 (55/1/1)]*

   (*a*) its resistance increases

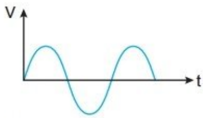
   (*b*) it becomes a *p*-type semiconductor

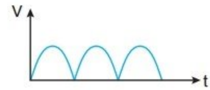
   (*c*) there will be more free electrons than holes in the semiconductor

   (*d*) dopant atoms become donor atoms.

2. **In the energy-band diagram of *n*-type Si, the gap between the bottom of the conduction band E_C and the donor energy level E_D is of the order of** **[*CBSE 2023 (55/1/1)*]**
(*a*) 10 eV (*b*) 1eV (*c*) 0.1 eV (*d*) 0.01 eV

3. **An *ac* source of voltage is connected in series with a *p-n* junction diode and a load resistor. The correct option for output voltage across load resistance will be** **[*CBSE 2023 (55/1/1)*]**

(*a*)


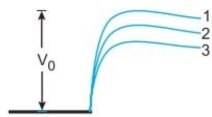
(*b*)


(*c*)


(*d*)

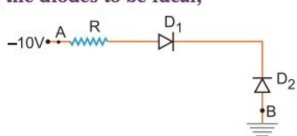

4. **The conductivity of a semiconductor increases with increase in temperature because** **[*NCERT Exemplar*]**
(*a*) number density of free current carriers increases.
(*b*) relaxation time increases.
(*c*) both number density of carriers and relaxation time increase.
(*d*) number density of current carriers increases, relaxation time decreases but effect of decrease in relaxation time is much less than increase in number density.

5. **In given figure, V_0 is the potential barrier across a *p-n* junction, when no battery is connected across the junction** **[*NCERT Exemplar*]**



(*a*) 1 and 3 both correspond to forward bias of junction
(*b*) 3 corresponds to forward bias of junction and 1 corresponds to reverse bias of junction
(*c*) 1 corresponds to forward bias and 3 corresponds to reverse bias of junction.
(*d*) 3 and 1 both correspond to reverse bias of junction.

6. **In given figure, assuming the diodes to be ideal,** **[*NCERT Exemplar*]**



(*a*) D_1 is forward biased and D_2 is reverse biased and hence currentflows from *A* to *B*.
(*b*) D_2 is forward biased and D_1 is reverse biased and hence no current flows from *B* to *A* and vice versa.
(*c*) D_1 and D_2 are both forward biased and hence current flows from *A* to *B*.
(*d*) D_1 and D_2 are both reverse biased and hence no current flows from *A* to *B* and vice versa.

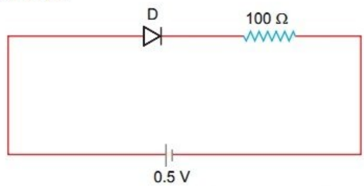
7. **In an extrinsic semiconductor, the number density of holes is 4×10^{20} m^{-3}. If the number density of intrinsic carriers is 1.2×10^{15} m^{-3} the number density of electrons in it is** **[*CBSE 2023 (55/2/1)*]**
(*a*) 1.8×10^{9} m^{-3} (*b*) 2.4×10^{10} m^{-3}
(*c*) 3.6×10^{9} m^{-3} (*d*) 3.2×10^{10} m^{-3}

8. **At a certain temperature in an intrinsic semiconductor the electrons and holes concentration is 1.5×10^{-16} m^{-3}. When it is doped with a trivalent dopant, hole concentration increases to 4.5×10^{-22} m^{-3}. In the doped semiconductor, the concentration of electrons (ne) will be** *[CBSE 2023 (55/3/1)]*
   (*a*) 3×10^6 m^{-3} (*b*) 5×10^7 m^{-3}
   (*c*) 5×10^9 m^{-3} (*d*) 6.75×10^{38} m^{-3}

9. **When an electric field is applied across a semiconductor** *[NCERT Exemplar]*
   (*a*) electrons move from lower energy level to higher energy level in the conduction band.
   (*b*) electrons move from higher energy level to lower energy level in the conduction band.
   (*c*) holes in the valence band move from higher energy level to lower energy level.
   (*d*) holes in the valence band move from lower energy level to higher energy level.

10. **When trivalent impurity is mixed in a pure semiconductor, the conduction is mainly due to**
   (*a*) electrons (*b*) holes
   (*c*) protons (*d*) positive ions

11. **The threshold voltage for a *p-n* junction diode used in the circuit is 0.7 V. The type of biasing and current in the circuit are:** *[CBSE 2023 (55/4/1)]*

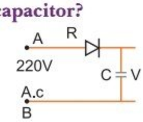


   (*a*) Forward biasing, 0 A (*b*) Reverse biasing, 0 A
   (*c*) Forward biasing, 5 mA (*b*) Reverse biasing, 2 mA

12. **The impurity atoms to be mixed in pure silicon to form *p*-type semiconductor are, of**
   (*a*) phosphorus (*b*) germanium
   (*c*) antimony (*d*) aluminium

13. **Holes are charge carriers in**
   (*a*) intrinsic semiconductor only (*b*) *p*-type semiconductor only
   (*c*) intrinsic and *p*-type semiconductors (*d*) *n*-type semiconductor

14. **A 220 V *ac* supply is connected between points *A* and *B* (shown in figure). What will be the potential difference *V* across the capacitor?** *[NCERT Exemplar]*



   (*a*) 220 V (*b*) 110 V (*c*) 0 V (*d*) $220\sqrt{2}$ V

15. **Hole is** *[NCERT Exemplar]*
   (*a*) an anti-particle of electron.
   (*b*) a vacancy created when an electron leaves a covalent bond.
   (*c*) absence of free electrons.
   (*d*) an artificially created particle.

16. **In the depletion region of a diode** *[NCERT Exemplar]*
   (*a*) there are no mobile charges
   (*b*) equal number of holes and electrons exist, making the region neutral.
   (*c*) recombination of holes and electrons has taken place.
   (*d*) immobile charged ions exist.

17 **The breakdown in a reverse biased *p-n* junction diode is more likely to occur due to** **[*NCERT Exemplar*]**

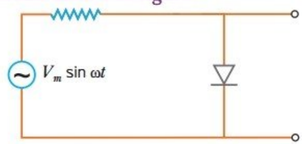
(*a*) large velocity of the minority charge carriers if the doping concentration is small.

(*b*) large velocity of the minority charge carriers if the doping concentration is large.

(*c*) strong electric field in a depletion region if the doping concentration is small.

(*d*) strong electric field in the depletion region if the doping concentration is large.

18. **The output of the given circuit shown in figure.** **[*NCERT Exemplar*]**



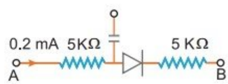
(*a*) would be zero at all times.

(*b*) would be like a half wave rectifier with positive cycles in output.

(*c*) would be like a half wave rectifier with negative cycles in output.

(*d*) would be like that of a full wave rectifier.

19. **In the circuit shown in figure, if the diode forward voltage drop is 0.3 V, the voltage difference between *A* and *B* is** **[*NCERT Exemplar*]**



(*a*) 1.3 V (*b*) 2.3 V (*c*) 0 (*d*) 0.5 V

20. **At equilibrium, in a *p-n* junction diode the net current is** **[*CBSE 2020 (55/2/1)*]**

(*a*) due to diffusion of majority charge carriers.

(*b*) due to drift of minority charge carriers.

(*c*) zero as diffusion and drift currents are equal and opposite.

(*d*) zero as no charge carriers cross the junction.

21. **In an *n*-type semiconductor, the donor energy level lies** **[*CBSE 2020 (55/2/1)*]**

(*a*) at the centre of the energy gap. (*b*) just below the conduction band.

(*c*) just above the valance band. (*d*) in the conduction band.

22. **The manifestation of band structure in solids is due to**

(*a*) Heisenberg's uncertainty principle (*b*) Pauli's exclusion principle

(*c*) Bohr's correspondence principle (*d*) Boltzmann's law

23. **A piece of copper and another of germanium are cooled from room temperature to 77 K. The resistance of** **[*HOTS*]**

(*a*) each of these decreases

(*b*) copper strip increases and that of germanium decreases

(*c*) copper strip decreases and that of germanium increases

(*d*) each of these increases

Answers

1. (*b*)	**2.** (*d*)	**3.** (*c*)	**4.** (*d*)	**5.** (*b*)	**6.** (*b*)	**7.** (*c*)
8. (*c*)	**9.** (*a*), (*c*)	**10.** (*b*)	**11.** (*a*)	**12.** (*d*)	**13.** (*c*)	**14.** (*d*)
15. (*b*)	**16.** (*a*), (*b*), (*d*)	**17.** (*a*), (*d*)	**18.** (*c*)	**19.** (*b*)	**20.** (*c*)	**21.** (*b*)
22. (*b*)	**23.** (*c*)					

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(a) *Both A and R are true and R is the correct explanation of A.*

(b) *Both A and R are true but R is not the correct explanation of A.*

(c) *A is true but R is false.*

(d) *A is false and R is also false.*

1. **Assertion** (*A*) : A pure semiconductor has negative temperature coefficient of resistance.

   Reason (*R*) : On raising the temperature, more charge carriers are released, conductance increases and resistance decreases. [*AIIMS 2010*]

2. **Assertion** (*A*) : In '*n*' type semiconductor, number density of electrons is greater than the number density of holes but the crystal maintains an overall charge neutrality.

   Reason (*R*) : The charge of electrons donated by donor atoms is just equal and opposite to that of the ionised donor. [*CBSE 2023 (55/4/1)*]

3. **Assertion** (*A*) : The forbidden energy gap between the valence and conduction bands is greater in silicon than in germanium.

   Reason (*R*) : Thermal energy produces fewer minority carriers in silicon than in germanium.

4. **Assertion** (*A*) : When the temperature of a semiconductor is increased, then its resistance decreases.

   Reason (*R*) : The energy gap between valence and conduction bands is very small for semiconductors.

5. **Assertion** (*A*) : The electrical conductivity of *n*-type semiconductor is higher than that of *p*-type semiconductor at a given temperature and voltage applied.

   Reason (*R*) : The mobility of electron is higher than that of hole.

6. **Assertion** (*A*) : A *p*-type semiconductor has negative charge on it.

   Reason (*R*) : *p*-type impurity atom has positive charge carrier (electrons) in it.

7. **Assertion** (*A*) : The energy gap between the valence band and conduction band is greater in silicon than in germanium.

   Reason (*R*) : Thermal energy produces fewer minority carriers in silicon than in germanium.

8. **Assertion** (*A*) : The temperature coefficient of resistance is positive for metals and negative for *p*-type semiconductors.

   Reason (*R*) : The effective charge carriers in metals are negatively charged electrons, whereas in *p*-type semiconductors, they are positively charged.

9. **Assertion** (*A*) : Diamond behaves such as an insulator.

   Reason (*R*) : There is a large energy gap between valence band and conduction bond of diamond.

10. **Assertion** (*A*) : At a fixed temperature, silicon will have a minimum conductivity when it has a smaller acceptor doping.

    Reason (*R*) : The conductivity of an intrinsic semiconductor is slightly higher than that of a lightly doped *p*-type. [*AIIMS 2010*]

Answers

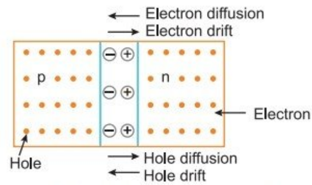
1. (*b*) 2. (*a*) 3. (*b*) 4. (*a*) 5. (*a*) 6. (*d*) 7. (*a*)
8. (*a*) 9. (*a*) 10. (*a*)

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Case-based/Passage-based Questions

Read the paragraph given below and answer the questions that follow:

Motions of the Charge Carriers: If you burst a helium -filled balloon, helium atoms will diffuse (spread) outward into the surrounding air. This happens because these are very few helium atoms in normal air. In more formal language, there is a helium density gradient at the balloon-air interface (the number density of helium atoms varies across the interface), the helium atoms move so as to reduce the gradient.



In same way, electrons on the *n*-side are close to the junction plane tend to diffuse across it and into the *p*-side, where there are very few free electrons. Similarly, holes on the *p*-side are close to the junction plane tend to diffuse across that plane and into the *n*-side, where there are very few holes. The motions of both the electrons and the holes contribute to a diffusion current ($I_{diff.}$).

(*i*) **Silicon is doped with which of the following to obtain *p*-type semiconductor?**

(*a*) Phosphorus (*b*) Gallium

(*d*) Germanium (*a*) Bismuth

(*ii*) **A semiconductor has an electron concentration of 6×10^{22} per m^3 and hole concentration of 8.5×10^9 per m^3. Then it is**

(*a*) *n*-type semiconductor (*b*) *p*-type semi conductor

(*c*) intrinsic semiconductor (*d*) conductor

(*iii*) **In a *p-n*-junction diode**

(*a*) the current in the reverse biased condition is generally very small $\sim \mu A$

(*b*) the current in the reverse biased condition is small but the forward biased current is independent of the bias voltage

(*c*) the reverse biased current is strongly dependent on the applied voltage

(*d*) the forward biased current is very small in comparison to reverse biased current

(*iv*) **In the middle of the depletion layer of a reverse biased *p-n* junction, the**

(*a*) electric field is zero (*b*) potential is maximum

(*c*) electric field is maximum (*d*) potential is zero

OR

The dominant mechanism for the motion of charge carriers in forward and reverse biased silicon junctions are

(*a*) drift in forward bias, diffusion in reverse bias

(*b*) diffusion in forward bias, drift in reverse bias

(*c*) diffusion in both forward and reverse bias

(*d*) drift in both forward and reverse bias

Explanations

(i) (b) Gallium being trivalent atom makes p-type semiconductor.

(ii) (a) The given semiconductor is n-type semiconductor as e^- concentration > hole concentration.

(iii) (a) In forward biased p-n-junction, external voltage decreases the potential barrier, so current is maximum. While in reversed biased p-n-junction, external voltage increases the potential barrier, so the current is very small of the order μA.

(iv) (a) When p-n junction is reversed biased, the width of the depletion layer becomes large and so, the electric field $\left(E = \frac{v}{d}\right)$ becomes very small, nearly zero.

(v) (b) diffusion in forward bias, drift in reverse bias.

CONCEPTUAL QUESTIONS

Q. 1. Name two intrinsic semiconductors.

Ans. Germanium, silicon

Q. 2. Name charge carriers in p-type semiconductor.

Ans. Holes.

Q. 3. Name charge carriers in n-type semiconductor.

Ans. Free electrons

Q. 4. If n_i is density of intrinsic charge carriers; n_h and n_e are densities of hole and electrons in extrinsic semiconductor, what is the relation among them?

Ans. $n_e n_h = n_i^2$

Q. 5. What is the net charge on (i) p-type semiconductor (ii) n-type semiconductor?

Ans. (i) Zero (ii) Zero

Q. 6. Why cannot we use Si and Ge in fabrication of visible LEDs? *[CBSE 2020 (55/1/1)]*

Ans. Si & Ge cannot be used for fabrication of visible LED because their energy gap is less 1.8 eV *[CBSE Marking Scheme 2020 (55/1/1)]* 1

Q. 7. How does the width of depletion region of a p–n junction vary if doping concentration is increased? *[CBSE Sample Paper 2021]*

Ans. When doping concentration is kept high in p–n junction, then there will be less space for electron to travel and equilibrium is achieved by recombination between charge carriers in nearby region. So, depletion width is decreased with doping.

Q. 8. At what temperature would an intrinsic semiconductor behave like a perfect insulator? *[CBSE East 2010]*

Ans. An intrinsic semiconductor behaves as a perfect insulator at temperature 0 K.

Q. 9. Can a slab of p-type semi-conductor be physically joined to another n-type semiconductor slab to form p-n junction? Justify your answer. *[CBSE 2020 (55/4/1)]*

Ans. No, slab will have roughness much larger than the inter atoms crystal spacing and hence continuous contact at the atomic level will not be possible. The junction will behave as a discontinuity for the flowing charge carriers. *[CBSE Marking Scheme 2020 (55/4/1)]* 1

Q. 10. What type of extrinsic semiconductor is formed when

(i) germanium is doped with indium?

(ii) silicon is doped with bismuth?

Ans. (i) Indium is trivalent, so germanium doped indium is a p-type semiconductor.

(ii) Bismuth is pentavalent, so silicon doped bismuth is an n-type semiconductor.

Q. 11. What happens to the width of depletion layer of a *p-n* junction when it is (*i*) forward biased, (*ii*) reverse biased? **[*CBSE Delhi 2011*]**

Ans. (*i*) When forward biased, the width of depletion layer decreases.

(*ii*) When reverse biased, the width of depletion layer increases.

Q. 12. In a *p-n* junction diode the forward bias resistance is low as compared to the reverse bias resistance. Give reason. **[*CBSE 2020 (55/4/1)*]**

Ans. In a *p-n* junction diode the forward bias has a low resistance because the barrier potential decreases and when the diode is reverse biased then the barrier potential increases hence it has a high resistance. **[*CBSE Marking Scheme 2020 (55/4/1)*] 1**

Q. 13. How are energy bands formed in a crystalline solid?

Ans. Isolated atoms have discrete energy levels. In a crystalline solid, due to the presence of large number of atoms, interatomic interactions take place. Due to this, energy levels get modified to energy bands.

Q. 14. Carbon and silicon have the same lattice structure. Then why is carbon an insulator but silicon a semiconductor? **[*CBSE 2023 (55/4/1)*]**

Ans. The 4 bonding of electrons of *C* and Si lie respectively, in the second and third orbit. Hence energy required to take out an electron from their atoms will be much less than for *C*. Hence number of free e^- for conduction in Si significant but negligibly small for *C*.

Q. 15. The energy gaps in the energy band diagrams of a conductor, semiconductor and insulator are E_1, E_2 and E_3. Arrange them in increasing order.

Ans. The energy gap in a conductor is zero, in a semiconductor is ≈ 1 eV and in an insulator is ≥ 3 eV.

$\therefore \quad E_1 = 0, E_2 = 1 \text{ eV}, E_3 \geq 3 \text{ eV}$

$\therefore \quad E_1 < E_2 < E_3$

Q. 16. In half wave rectification, what is the output frequency if input frequency is 25 Hz? **[*CBSE Sample Paper 2021*]**

Ans. For a half wave rectifier, the output frequency is equal to the input frequency. So, the frequency after rectification is 25 Hz.

Q. 17. Can the potential barrier across a *p-n* junction be measured by simply connecting a voltmeter across the junction? **[*HOTS*] [*NCERT Exemplar*]**

Ans. No, because the voltmeter must have a resistance very high compared to the junction resistance, the latter being nearly infinite.

Q. 18. When a voltage drop across a *p–n* junction diode is increased from 0.70 V to 0.71 V, the change in the diode current is 10 mA .What is the dynamic resistance of diode? **[*CBSE Sample Paper 2021*]**

Ans. Dynamic resistance $= \dfrac{\Delta V}{\Delta I} = \dfrac{0.71 - 0.70}{10 \times 10^{-3}} = \dfrac{0.01}{10^{-2}} = 1\,\Omega$

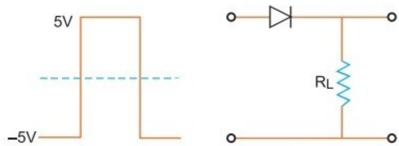
Q. 19. Why are elemental dopants for Silicon or Germanium usually chosen from group 13 or group 15? **[*NCERT Exemplar*]**

Ans. The size of dopant atoms should be such as not to distort the pure semiconductor lattice structure and yet easily contribute a charge carrier on forming covalent bonds with Si or Ge.

Q. 20. Sn, C, Si and Ge are all group 14 elements. Yet, Sn is a conductor, C is an insulator while Si and Ge are semiconductors. Why? **[*NCERT Exemplar*]**

Ans. If the valance and conduction bands overlap (no energy gap), the substance is referred as a conductor. For insulator the energy gap is large and for semiconductor the energy gap is moderate. The energy gap for Sn is 0 eV, for C is 5.4 eV, for Si is 1.1 eV and for Ge is 0.7 eV, related to their atomic size.

Q. 21. Draw the output signal in a *p-n* junction diode when a square input signal of 10 V as shown in the figure is applied across it.
[*CBSE 2019 (55/5/1)*]

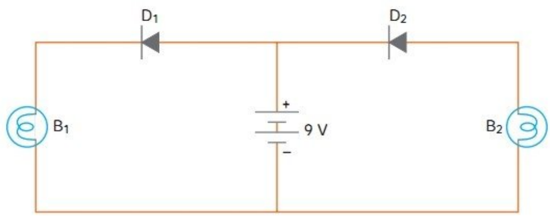


Ans.

Q. 22. How does one understand the temperature dependance of resistivity of a semiconductor?
[*CBSE (F) 2010*]

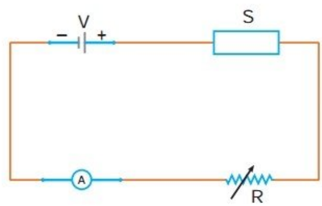
Ans. When temperature increases, covalent bonds of neighbouring atoms break and charge carrier become free to cause conduction, so resistivity of semi-conductor decreases with rise of temperature.

Q. 23. In the following diagram, which bulb out of B_1 and B_2 will glow and why? **[*CBSE (AI) 2017*]**



Ans. Bulb B_1 will glow as diode D_1 is forward biased.

Q. 24. In the following diagram '*S*' is a semiconductor. Would you increase or decrease the value of *R* to keep the reading of the ammeter A constant when S is heated? Give reason for your answer.
[*CBSE (AI) 2017*]



Ans.

When S is heated, the temperature increases. The resistivity decreases. The resistance of the circuit decreases so more current tend to flow. In order to keep the current value as constant the resistance R should be increased.
So R is increased to keep the ammeter reading as constant.

[Topper's Answer 2017]

Q. 25. What happens when a forward bias is applied to a *p-n* junction? **[*CBSE Panchkula 2015*]**

Ans. The direction of the applied voltage (V) is opposite to the built-in potential V_0. As a result, depletion layer width decreases and the barrier height is reduced to $V_0 - V$.

Very Short Answer Questions

Each of the following questions are of 2 marks.

Q. 1. Distinguish between a metal and an insulator on the basis of energy band diagrams.

[CBSE (F) 2014]

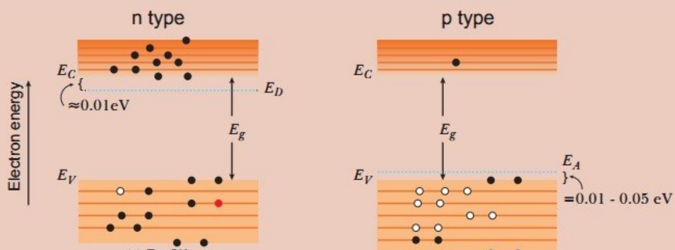
Ans.

	Metal	Insulators
(*i*)	Conduction band and valence band overlap each other.	There is large energy gap between conduction band and valence band.
(*ii*)	Conduction band is partially filled and valence band is partially empty.	Conduction band is empty. This is because no electrons can be excited to it from valence band.

Q. 2. Draw energy band diagrams of *n*-type and *p*-type semiconductors at temperature T > 0 K, depicting the donor and acceptor energy levels. Mention the significance of these levels.

[CBSE 2022 (55/1/1), Term-2, 2023 (55/2/1)]

Ans.



(a) T > OK
One thermally generated electron-hole pair + 9 electrons from donor atoms

(b) T > OK

1

Significance

n-type semiconductors – small energy gap between donor level and conduction band which can be easily covered by thermally excited electrons. 1

p- type semiconductors - small energy gap between acceptor level and valence band which can be easily covered by thermally excited electrons.

Alternatively

The conductivity of semiconductor is improved with the creation of donor and acceptor levels.

[CBSE Marking Scheme 2022 (55/1/1), Term-2]

Q. 3. Answer the following giving reasons:

(*a*) A *p-n* junction diode is damaged by a strong current.

(*b*) Impurities are added in intrinsic semiconductors. *[CBSE 2023 (55/2/1)]*

Ans. (*a*) When a strong current passes through the semiconductor it heats up the crystal and covalent bond are broken. Hence *p-n* junction diode is damaged.

(*b*) By the process of doping, impurities are added in intrinsic semiconductors to increase the conductivity.

Q. 4. How is forward biasing different from reverse biasing in a *p-n* junction diode?

[*CBSE Delhi 2011*]

Ans. **1. Forward Bias:**

(*i*) Within the junction diode the direction of applied voltage is opposite to that of built-in potential.

(*ii*) The current is due to diffusion of majority charge carriers through the junction and is of the order of milliamperes.

(*iii*) The diode offers very small resistance in the forward bias.

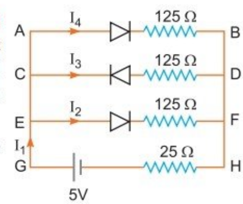
2. Reverse Bias:

(*i*) The direction of applied voltage and barrier potential is same.

(*ii*) The current is due to leakage of minority charge carriers through the junction and is very small of the order of μA

(*iii*) The diode offers very large resistance in reverse bias.

Q. 5. If each diode in figure has a forward bias resistance of 25 Ω and infinite resistance in reverse bias, what will be the values of current I_1, I_2, I_3 and I_4? **[*HOTS*] [*NCERT Exemplar*]**



Ans. I_3 is zero as the diode in that branch is reverse biased. Resistance in the branch *AB* and *EF* are each $(125 + 25)\ \Omega = 150\ \Omega$

As *AB* and *EF* are identical parallel branches, their effective resistance is $\frac{150}{2} = 75\ \Omega$

$\therefore$ Net resistance in the circuit $= (75 + 25)\ \Omega = 100\ \Omega$

$\therefore$ Current $I_1 = \frac{5}{100} = \mathbf{0.05\ A}$

As resistances of *AB* and *EF* are equal, and $I_1 = I_2 + I_3 + I_4$, $I_3 = \mathbf{0}$

$\therefore \quad I_2 = I_4 = \frac{0.05}{2} = \mathbf{0.025\ A}$

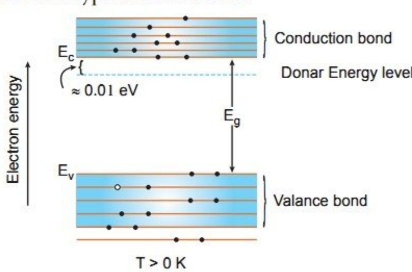
Q. 6. In a pure semiconductor crystal of Si, if antimony is added then what type of extrinsic semiconductor is obtained. Draw the energy band diagram of this extrinsic semiconductor so formed. **[*CBSE Sample Paper 2022, Term-2*]**

OR

A germanium crystal is doped with antimony. With the help of energy-band diagram, explain how the conductivity of the doped crystal is affected. **[*CBSE 2023 (55/4/1)*]**

Ans. As given in the statement antimony is added to pure Si/Ge crystal, then a *n*-type extrinsic semiconductor would be so obtained, Since antimony(Sb) is a pentavalent impurity. After doping with antimony, the number of conduction electrons can be made much larger than the number of holes. Due to this conductivity of the doped crystal increases.

Energy level diagram of *n*-type semiconductor:



Q. 7. A germanium *p-n* junction is connected to a battery with milliammeter in series. What should be the minimum voltage of battery so that current may flow in the circuit? **[*HOTS*]**

Ans. The internal potential barrier of germanium is 0.3 V, therefore to overcome this barrier the potential of battery should be equal to or more than 0.3 V.

Therefore, the minimum voltage of battery = **0.3 V.**

Q. 8. Briefly explain how the diffusion and drift currents contribute to formation of potential barrier in a *p-n* junction diode. **[*CBSE 2023 (55/1/1)*]**

OR

Explain briefly the two processes that occur in *p-n* junction region to create a potential barrier. **[*CBSE 2020 (55/3/1)*]**

Ans. **Diffusion:** During the formation of *p-n* junction, due to the concentration gradient across the *p* and *n* sides, the motion of majority charge carriers give rise to diffusion current. **1**

Drift: Due to the electric field developed at the junction, the motion of the minority charge carriers due to electric field is called drift. **1**

With the passage of time, diffusion current decreases whereas drift current increases and balance each other. This, creates a potential barrier. **[*CBSE Marking Scheme 2020 (55/3/1)*]**

Q. 9. Explain the property of a *p-n* junction which makes it suitable for rectifying alternating voltages. Differentiate between a half-wave and a full-wave rectifier. **[*CBSE 2023 (55/3/1)*]**

Ans. Rectification means conversion of *ac* into *dc*. A *p-n* diode acts as a rectifier because an *ac* changes polarity periodically and a *p-n* diode allows the current to pass only when it is forward biased. This characteristics property makes the diode suitable for rectification.

Difference between Half wave and Full wave rectifier

	Half wave rectifier	Full wave rectifier
(*i*)	It converting the one-half cycles of *AC* input to *DC* output.	It converting both the half cycles or complete full cycle of *AC* input in to *DC* output.
(*ii*)	Ripple factor of a half-wave rectifier is more.	Ripple factor of a full wave rectifier is less.
(*iii*)	Single *p–n* junction diode is used for rectification.	At least two or four diode may used for rectification depending on the type of circuit.

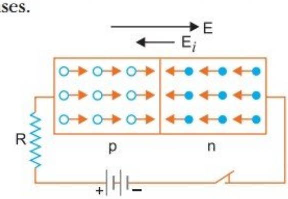
Q. 10. What is meant by doping of an intrinsic semiconductor? Name the two types of atoms used for doping of Ge/Si. **[*CBSE 2022 (55/3/1), Term-2*]**

Ans. **Doping:** The deliberate addition of a desirable impurity in pure Si/Ge semiconductor to enhance conductivity is called doping.

Types of atoms: (*i*) Pentavalent – Arsenic (As) (*ii*) Trivalent – Boron (B).

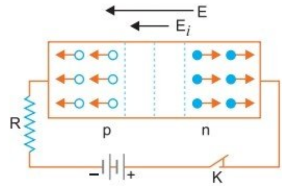
Q. 11. What will the effect of (*i*) forward biasing, and (*ii*) reverse biasing be on the width of depletion layer in *p-n* junction diode? **[*CBSE 2023 (55/4/1)*]**

Ans. (*i*) Under forward biasing the applied potential difference causes a field which acts opposite to the potential barrier. This results in reducing the potential barrier, and hence the width of depletion layer decreases.



Forward current

(*ii*) Under reverse biasing the applied potential difference causes a field which is in the same direction as the field due to internal potential barrier. This results in an increase in barrier voltage and hence the width of depletion layer increases.



Reverse current

Short Answer Questions

Each of the following questions are of 3 marks.

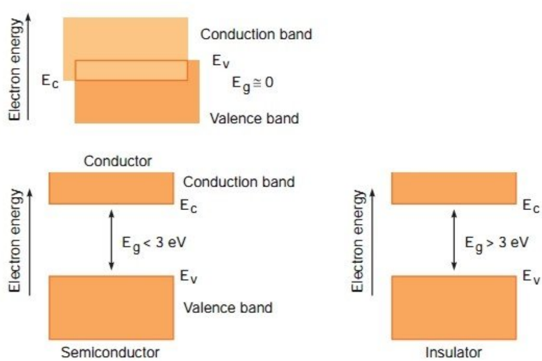
Q. 1. What are energy bands? Write any two distinguishing features between conductors, semiconductors and insulators on the basis of energy band diagrams.

[*CBSE (AI) 2014, North 2016*]

OR

Draw the necessary energy band diagrams to distinguish between conductors, semiconductors and insulators. How does the change in temperature affect the behaviour of these materials? Explain briefly. [*CBSE Patna 2015, 2020 (55/4/1)*]

Ans. Energy Bands: In a solid, the energy of electrons lie within certain range. The energy levels of allowed energy are in the form of bands, these bands are separated by regions of forbidden energy called band gaps.



Distinguishing features:

(*a*) In conductors: Valence band and conduction band overlap each other.

In semiconductors: Valence band and conduction band are separated by a small energy gap.

In insulators: They are separated by a large energy gap.

(*b*) In conductors: Large number of free electrons are available in conduction band.

In semiconductors: A very small number of electrons are available for electrical conduction.

In insulators: Conduction band is almost empty *i.e.*, no electron is available for conduction.

Effect of Temperature:

(*i*) In conductors: At high temperature, the collision of electrons become more frequent with the atoms/molecules at lattice site in the metals as a result the conductivity decreases (or resistivity increases).

(*ii*) In semiconductors: As the temperature of the semiconducting material increases, more electron hole pairs becomes available in the conduction band and valance band, and hence the conductivity increases or the resistivity decreases.

(*iii*) In insulators: The energy band between conduction band and valance band is very large, so it is unsurpassable for small temperature rise. So, there is no change in their behaviour.

Q. 2. Distinguish between 'intrinsic' and 'extrinsic' semiconductors.

[CBSE Delhi 2015, (F) 2017, 2023 (55/1/1)]

Ans.

	Intrinsic semiconductor	**Extrinsic semiconductor**
(*i*)	It is a semiconductor in pure form.	It is a semiconductor doped with trivalent or pentavalent impurity atoms.
(*ii*)	Intrinsic charge carriers are electrons and holes with equal concentration.	The two concentrations are unequal in it. There is excess of electrons in *n*-type and excess of holes in *p*-type semiconductors.
(*iii*)	Current due to charge carriers is feeble (of the order of μA).	Current due to charge carriers is significant (of the order of mA).

Q. 3. Name the important process that occurs during the formation of a *p-n* junction. Explain briefly, with the help of a suitable diagram, how a *p-n* junction is formed. Define the term 'barrier potential'. ***[CBSE (F) 2011, Central 2016]***

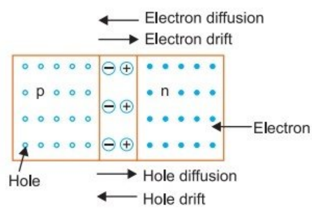
OR

Describe briefly, with the help of a diagram, the role of the two important processes involved in the formation of a *p-n* junction.

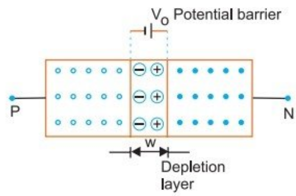
[CBSE (AI) 2012, Bhubaneshwar 2015, 2020 (55/4/1), 2023 (55/3/1), (55/4/1)]

Ans. Two important processes occurring during the formation of a *p-n* junction are (*i*) diffusion and (*ii*) drift.

(*i*) Diffusion: In *n*-type semiconductor, the concentration of electrons is much greater as compared to concentration of holes; while in *p*-type semiconductor, the concentration of holes is much greater than the concentration of electrons. When a *p-n* junction is formed, then due to concentration gradient, the holes diffuse from *p*-side to *n*-side ($p \rightarrow n$) and electrons diffuse from *n*-side to *p*-side ($n \rightarrow p$). This motion of charge carriers gives rise to diffusion current across the junction.



(*ii*) **Drift:** The drift of charge carriers occurs due to electric field. Due to built in potential barrier, an electric field directed from *n*-region to *p*-region is developed across the junction. This field causes motion of electrons on *p*-side of the junction to *n*-side and motion of holes on *n*-side of junction to *p*-side. Thus a drift current starts. This current is opposite to the direction of **diffusion current.**



Potential barrier: During the formation of a *p*-*n* junction the electrons diffuse from *n*-region to *p*-region and holes diffuse from *p*-region to *n*-region. This forms recombination of charge carriers. In this process immobile positive ions are collected at a junction toward *n*-region and negative ions at a junction toward *p*-region. This causes a potential difference across the unbiased junction. This is called potential barrier.

Q. 4. Draw *V* – *I* characteristics of a *p*–*n* junction diode. Answer the following questions, giving reasons:

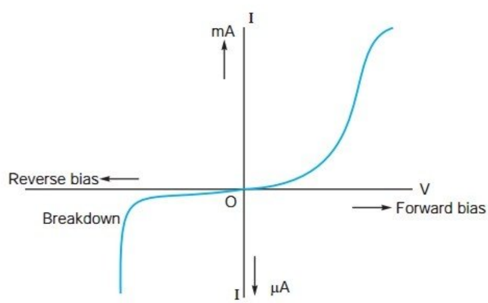
(*i*) Why is the current under reverse bias almost independent of the applied potential upto a critical voltage?

(*ii*) Why does the reverse current show a sudden increase at the critical voltage?

[*CBSE (AI) 2013, CBSE 2019*]

Ans. (*i*) In the reverse biasing, the current of order of μA is due to movement/drifting of minority charge carriers from one region to another through the junction.

A small applied voltage is sufficient to sweep the minority charge carriers through the junction. So, reverse current is almost independent of critical voltage.



(*ii*) At critical voltage (or breakdown voltage), a large number of covalent bonds break, resulting in the increase of large number of charge carriers. Hence, current increases at critical voltage.

Q. 5. The current in the forward bias is known to be more (~mA) than the current in the reverse bias (~μA). What is the reason, then, to operate the photodiode in reverse bias?

[*HOTS*][*CBSE Delhi 2012*]

Ans. Consider the case of *n*-type semiconductor. The majority carrier (electron) density is larger than the minority hole density, *i.e.*, $n >> p$.

On illumination, the no. of both types of carriers would equally increase in number as

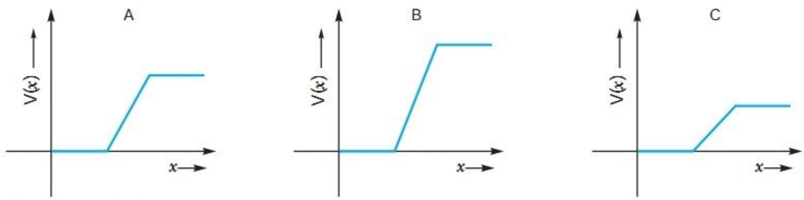
$n' = n + \Delta n, p' = p + \Delta p$

But $\Delta n = \Delta p$ and $n >> p$

Hence, the fractional change in majority carrier, *i.e,* $\frac{\Delta n}{n} << \frac{\Delta p}{p}$ (fractional change in minority carrier)

Fractional change due to photo-effects on minority carrier dominated reverse bias current is more easily measurable than the fractional change in majority carrier dominated forward bias current. Hence photodiodes are used in reverse bias condition for measuring light intensity.

Q. 6. The graph of potential barrier versus width of depletion region for an unbiased diode is shown in *A*. In comparison to *A*, graphs *B* and *C* are obtained after biasing the diode in different ways. Identify the type of biasing in *B* and *C* and justify your answer. [*CBSE Sample Paper 2016, 2023*]



Ans. B : Reverse biased

Justification: When an external voltage V is applied across the semiconductor diode such that n-side is positive and p-side is negative, the direction of applied voltage is same as the direction of barrier potential. As a result, the barrier height increases and the depletion region widens due to the change in the electric field. The effective barrier height under reverse bias is (V_0+V).

C : Forward biased

Justification: When an external voltage V is applied across a diode such that p-side is positive and n-side is negative, the direction of applied voltage (V) is opposite to the barrier potential (V_0). As a result, the depletion layer width decreases and the barrier height is reduced. The effective barrier height under forward bias is $(V_0 - V)$.

Q. 7. A semiconductor has equal electron and hole concentration of 2×10^8 / m^3. On doping with a certain impurity, the hole concentration increases to 4×10^{10} / m^3.

(*i*) What type of semiconductor is obtained on doping?

(*ii*) Calculate the new electron and hole concentration of the semiconductor.

(*iii*) How does the energy gap vary with doping?

Ans. Given $n_e = 2 \times 10^8 / \text{m}^3, n_h = 4 \times 10^{10} / \text{m}^3$

(*i*) The majority charge carriers in doped semiconductor are holes, so semiconductor obtained is p-type semiconductor.

(*ii*) $n_e n_h = n_i^2 \Rightarrow n_e = \frac{n_i^2}{n_h} = \frac{(2\times10^8)^2}{4\times10^{10}} = \mathbf{10^6/m^3}$

New electron concentration $= 10^6 / \text{m}^3$

hole concentration $= 4 \times 10^{10} / \text{m}^3$

(*iii*) Energy gap decreases on doping.

Long Answer Questions

Each of the following questions are of 5 marks.

Q. 1. **(*a*) State briefly the processes involved in the formation of *p-n* junction explaining clearly how the depletion region is formed.**

(*b*) Using the necessary circuit diagrams, show how the V–I characteristics of a *p-n* junction are obtained in (*i*) Forward biasing (*ii*) Reverse biasing

How are these characteristics made use of in rectification? *[CBSE Delhi 2014]*

OR

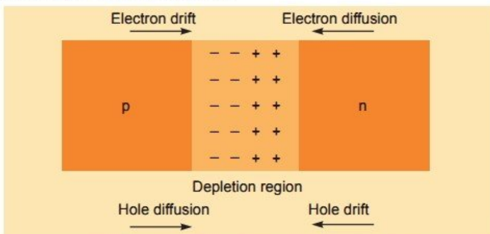
Draw the circuit arrangement for studying the *V–I* characteristics of a *p-n* junction diode (*i*) in forward bias and (*ii*) in reverse bias. Draw the typical *V–I* characteristics of a silicon diode.

Describe briefly the following terms: *[CBSE 2023 (55/1/1)]*

(*i*) "minority carrier injection" in forward bias

(*ii*) "breakdown voltage" in reverse bias. *[CBSE Chennai 2015]*

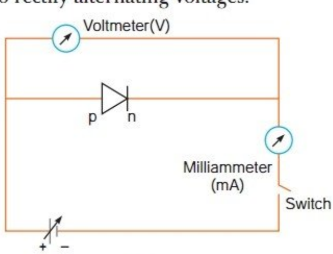
Ans. (*a*)



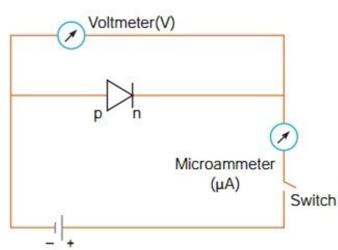
Two processes occur during the formation of a p-n junction are diffusion and drift. Due to the concentration gradient across p and n-sides of the junction, holes diffuse from p-side to n-side ($p \rightarrow n$) and electrons diffuse from n-side to p-side ($n \rightarrow p$). This movement of charge carriers leaves behind ionised acceptors (negative charge immobile) on the p-side and donors (positive charge immobile) on the n-side of the junction. This space charge region on either side of the junction together is known as depletion region.

(*b*) The circuit arrangement for studying the V–I characteristics of a diode are shown in Fig. (*a*) and (*b*). For different values of voltages the value of current is noted. *A* graph between V and I is obtained as in Figure (*c*).

From the V–I characteristic of a junction diode it is clear that it allows current to pass only when it is forward biased. So if an alternating voltage is applied across a diode the current flows only in that part of the cycle when the diode is forward biased. This property is used to rectify alternating voltages.



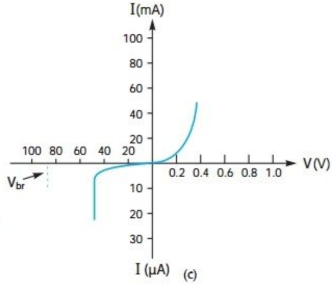
(a)



(b)

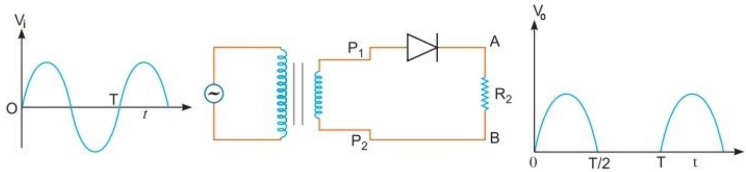
(*i*) **Minority Carrier Injection:** Due to the applied voltage, electrons from *n*-side cross the depletion region and reach *p*-side (where they are minority carriers). Similarly, holes from *p*-side cross this junction and reach the *n*-side (where they are minority carriers). This process under forward bias is known as minority carrier injection.

(*ii*) **Breakdown Voltage:** It is a critical reverse bias voltage at which current is independent of applied voltage.



Q. 2. Explain, with the help of a circuit diagram, the working of a *p-n* junction diode as a half-wave rectifier. [*CBSE (AI) 2014*]

Ans.



Working

(*i*) During positive half cycle of input alternating voltage, the diode is forward biased and a current flows through the load resistor R_L and we get an output voltage.

(*ii*) During other negative half cycle of the input alternating voltage, the diode is reverse biased and it does not conduct (under break down region).

Hence, *ac* voltage can be rectified in the pulsating and unidirectional voltage.

Q. 3. State the principle of working of *p-n* diode as a rectifier. Explain with the help of a circuit diagram, the use of *p-n* diode as a full wave rectifier. Draw a sketch of the input and output waveforms. [*CBSE Delhi 2012, 2020 (55/3/2)*]

OR

Draw a circuit diagram of a full wave rectifier. Explain the working principle. Draw the input/output waveforms indicating clearly the functions of the two diodes used.

[*CBSE (AI) 2011, 2020 (55/1/3)*]

OR

With the help of a circuit diagram, explain the working of a junction diode as a full wave rectifier. Draw its input and output waveforms. Which characteristic property makes the junction diode suitable for rectification? [*CBSE Ajmer 2015, North 2016, 2023 (55/4/1)*]

OR

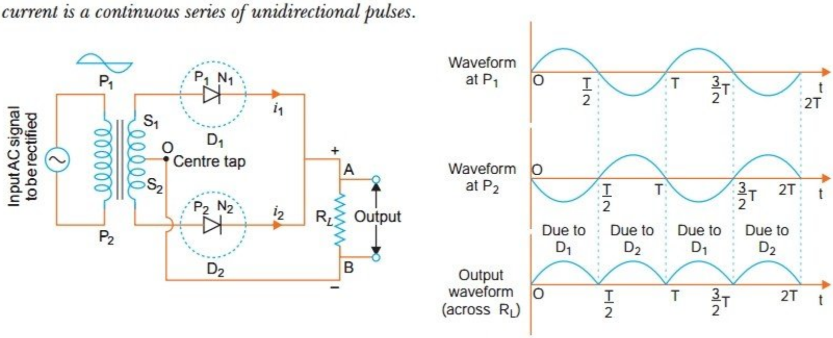
Draw the circuit diagram of a full wave rectifier and explain its working. Also give the input and output waveforms. [*CBSE Delhi 2019, 2020, (55/1/3), 2022 (55/2/1), Term-2*]

OR

Explain with a proper diagram how an ac signal can be converted into *dc* (pulsating) signal with output frequency as double than the input frequency using *p–n* junction diode. Give its input and output waveforms. [*CBSE Sample Paper 2022, Term-2*]

Ans. **Rectification:** Rectification means conversion of *ac* into *dc*. A *p-n* diode acts as a rectifier because an *ac* changes polarity periodically and a *p-n* diode allows the current to pass only when it is forward biased. This makes the diode suitable for rectification.

Working: The ac input voltage across secondary S_1 and S_2 changes polarity after each half cycle. Suppose during the first half cycle of input ac signal, the terminal S_1 is positive relative to centre tap O and S_2 is negative relative to O. Then diode D_1 is forward biased and diode D_2 is reverse biased. Therefore, diode D_1 conducts while diode D_2 does not. The direction of current (i_1) due to diode D_1 in load resistance R_L is directed from A to B In next half cycle, the terminal S_1 is negative and S_2 is positive relative to centre tap O. The diode D_1 is reverse biased and diode D_2 is forward biased. Therefore, diode D_2 conducts while D_1 does not. The direction of current (i_2) due to diode D_2 in load resistance R_L is still from A to B. Thus, the current in load resistance R_L is in the same direction for both half cycles of input ac voltage. Thus *for input ac signal the output current is a continuous series of unidirectional pulses*.



In a full wave rectifier, if input frequency is f hertz, then output frequency will be $2f$ hertz because for each cycle of input, two positive half cycles of output are obtained.

Q. 4. (*a*) Distinguish between an intrinsic semiconductor and a *p*-type semiconductor. Give reason why a *p*-type semiconductor is electrically neutral, although $n_h >> n_e$.

(*b*) Explain, how the heavy doping of both *p*-and *n*-sides of a *p-n* junction diode results in the electric field of the junction being extremely high even with a reverse bias voltage of a few volts. **[*CBSE (F) 2013*]**

Ans. (*a*)

	Intrinsic semiconductor	*p*-type semiconductor
(*i*)	It is a semiconductor in pure form.	It is a semiconductor doped with trivalent impurity atoms (Like Al, Ga, *etc*.).
(*ii*)	Intrinsic charge carriers are electrons and holes with equal concentration.	There is excess of holes in *p*-type semiconductors as majority charge carrier.
(*iii*)	Current due to charge carriers is feeble (of the order of μA).	Current due to charge carriers is significant (of the order of mA).

When the trivalent imurities are doped in to the tetravalent pure semiconductor like Si or Ge then the fourth electron of the Si or Ge needs to be bounded then the electron in the outermost shell of the Si or Ge can jump in to the vacancy and create hole on its own atom. But the number of the electrons and holes are same in magnitude and apposite in sign. Hence a *p*-type semiconductor is electrically neutral.

(*b*) If *p*-type and *n*-type semiconductor are heavily doped. Then due to diffusion of electrons from *n*-region to *p*-region, and of holes from *p*-region to *n*-region, a depletion region formed of size of order less than 1 μm. The electric field directing from *n*-region to *p*-region produces a reverse bias voltage of about 5 V and electric field becomes very large.

$$E = \frac{\Delta V}{\Delta x} = \frac{5\text{V}}{1\mu\text{m}} \approx \mathbf{5 \times 10^6\ V/m}$$

Questions for Practice

1. **Choose and write the correct option in the following questions.**

   (*i*) Carbon, silicon and germanium have four valence electrons each. These are characterised by valence and conduction bands, separated by energy band gap respectively equal to $(E_g)_C$, $(E_g)_{Si}$ and $(E_g)_{Ge}$. Which of the following statement is true?

   (*a*) $(E_g)_{Si} < (E_g)_{Ge} < (E_g)_C$ (*b*) $(E_g)_C < (E_g)_{Ge} > (E_g)_{Si}$
   (*c*) $(E_g)_C > (E_g)_{Si} > (E_g)_{Ge}$ (*d*) $(E_g)_C = (E_g)_{Si} = (E_g)_{Ge}$

   (*ii*) If a *p-n* junction diode is reverse biased, **[*CBSE 2023 (55/3/1)*]**

   (*a*) the potential barrier is lowered. (*b*) the potential barrier remains unaffected.
   (*c*) the potential barrier is raised. (*d*) the current is mainly due to majority carriers.

   (*iii*) When a forward bias is applied to a *p-n* junction, it

   (*a*) raises the potential barrier (*b*) reduces the majority carrier current to zero
   (*c*) lowers the potential barrier (*d*) none of the above

   (*iv*) Pieces of copper and of silicon are initially at room temperature. Both are heated to temperature *T*. The conductivity of **[*CBSE 2023 (55/2/1)*]**

   (*a*) both increases (*b*) both decreases
   (*c*) copper increases and silicon decreases (*d*) copper decreases and silicon increases

   (*v*) The formation of depletion region in a *p-n* junction diode is due to **[*CBSE 2023 (55/2/1)*]**

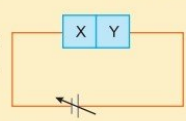
   (*a*) movement of dopant atoms (*b*) diffusion of both electrons and holes
   (*c*) drift of electrons only (*d*) drift of holes only

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

   (a) ***Both A and R are true and R is the correct explanation of A.***
   (b) ***Both A and R are true but R is not the correct explanation of A.***
   (c) ***A is true but R is false.***
   (d) ***A is false and R is also false.***

   Assertion (*A*) : A *p-n* junction diode can be used even at ultra high frequencies.
   Reason (*R*) : Capacitive reactance of *p-n* junction diode increases as frequency increases.

3. Explain the formation of depletion region in a *p-n* junction. **[*CBSE Sample Paper 2022 (55/2/1)*]**
4. Why is an intrinsic semiconductor deliberately conversed into an extrinsic semiconductor by adding impurity atoms? **[*CBSE 2020 (55/3/1)*]**
5. Draw the circuit arrangement for studying the *V-I* characteristics of a *p-n* junction diode in forward bias and reverse bias. Show the plot of *V-I* characteristic of a silicon diode. **[*CBSE 2023 (55/1/1)*]**
6. What happens when a forward bias is applied to a *p-n* junction?
7. Two semiconductor materials *X* and *Y* shown in the alongside figure, are made by doping a germanium crystal with indium and arsenic respectively. The two are joined end to end and connected to a battery as shown.

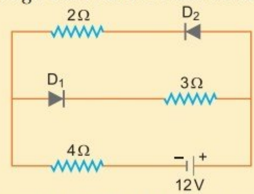


   (*i*) Will the junction be forward biased or reverse biased?
   (*ii*) Sketch a *V-I* graph for this arrangement.

8. Draw the energy band diagram when intrinsic semiconductor (Ge) is doped with impurity atoms of Antimony (Sb). Name the extrinsic semiconductor so obtained and majority charge carriers in it. **[*CBSE Sample Paper 2021, 2022, Term-2*]**

9. Explain the terms 'depletion layer' and 'potential barrier' in a p-n junction diode. How are the (*a*) width of depletion layer, and (*b*) value of potential barrier affected when the p-n junction is forward biased? [*CBSE 2020 (55/1/1)*]

10. The circuit shown in the figure has two oppositely connected ideal diodes connected in parallel. Find the current flowing through each diode in the circuit.



11. Write two characteristic features to distinguish between n-type and p-type semiconductors. [*CBSE (F) 2012*]

12. Draw energy band diagrams of an n-type and p-type semiconductor at temperature $T > 0$ K. Mark the donor and acceptor energy levels with their energies. [*CBSE (F) 2014, 2020 (55/3/3)*]

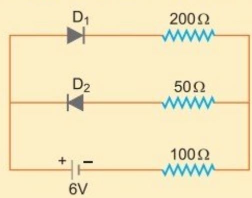
13. Three photo diodes D_1, D_2 and D_3 are made of semiconductors having band gaps of 2.5 eV, 2 eV and 3 eV, respectively. Which ones will be able to detect light of wavelength 6000 Å? [*HOTS*] [*NCERT Exemplar*]

14. Draw $V - I$ characteristics of p-n junction diode. Explain how these characteristics make a diode suitable for rectification. [*CBSE 2023 (55/4/1)*]

15. Write the two processes that take place in the formation of p-n junction. Explain with the help of a diagram, the formation of depletion region and barrier potential in a p-n junction. [*CBSE Delhi 2017*]

16. (*a*) Draw *V-I* characteristics of a p-n junction diode. Explain, why the current under reverse bias is almost independent of the applied voltage up to the critical voltage. [*CBSE 2020 (55/2/1)*]

(*b*) The circuit shown in the figure contains two diodes each with a forward resistance of 50 Ω and infinite backward resistance. Calculate the current in the 100 Ω resistance.



Answers

1. (*i*) (*c*) (*ii*) (*c*) (*iii*) (*c*) (*iv*) (*d*) (*v*) (*b*)
2. (*c*)
10. 2 A 16. (*b*) 0.0171 A

PART–B

- CBSE Sample Question Paper–2024 (Solved)
- CBSE Sample Question Paper–2023 (Unsolved)
- CBSE Examination Paper-2023 (Solved)
- CBSE Practice Question Paper (Unsolved)

CBSE Sample Question Paper–2024 (Solved)

Time allowed: 3 hours **Maximum marks: 70**

General Instructions:

(i) *There are 33 questions in all. All questions are compulsory.*

(ii) *This question paper has five sections: Section **A**, Section **B**, Section **C**, Section **D** and Section **E**.*

(iii) *All the sections are compulsory.*

(iv) ***Section A** contains sixteen questions, twelve MCQ and four Assertion Reasoning based of 1 mark each, **Section B** contains five questions of two marks each, **Section C** contains seven questions of three marks each, **Section D** contains two case study based questions of four marks each and **Section E** contains three long answer questions of five marks each.*

(v) *There is no overall choice. However, an internal choice has been provided in one question in **Section B**, one question in **Section C**, one question in each CBQ in **Section D** and all three questions in **Section E**. You have to attempt only one of the choices in such questions.*

(vi) *Use of calculators is **not** allowed.*

(vii) *You may use the following values of physical constants where ever necessary*

(*a*) $c = 3 \times 10^8$ m/s

(*b*) $m_e = 9.1 \times 10^{-31}$ kg

(*c*) $e = 1.6 \times 10^{-19}$ C

(*d*) $\mu_0 = 4\pi \times 10^{-7}$ T mA^{-1}

(*e*) $h = 6.63 \times 10^{-34}$ Js

(*f*) $\varepsilon_0 = 8.854 \times 10^{-12}$ C^{2}N^{-1}m^{-2}

(*g*) Avogadro's number $= 6.023 \times 10^{23}$ per gram mole

SECTION–A

1. Which of the following is not the property of an equipotential surface?

(*a*) They do not cross each other.

(*b*) The work done in carrying a charge from one point to another on an equipotential surface is zero.

(*c*) For a uniform electric field, they are concentric spheres.

(*d*) They can be imaginary spheres.

2. An electric dipole placed in an electric field of intensity 2×10^5 N/C at an angle of 30° experiences a torque equal to 4 Nm. The charge on the dipole of dipole length 2 cm is

(*a*) 7 μC (*b*) 8 mC (*c*) 2 mC (*d*) 5 mC

3. A metallic plate exposed to white light emits electrons. For which of the following colours of light, the stopping potential will be maximum?

(*a*) Blue (*b*) Yellow (*c*) Red (*d*) Violet

4. When alpha particles are sent through a thin gold foil, most of them go straight through the foil, because

(*a*) alpha particles are positively charged

(*b*) the mass of an alpha particle is more than the mass of an electron

(*c*) most of the part of an atom is empty space

(*d*) alpha particles move with high velocity

5. **An electron is moving along positive *x*-axis in a magnetic field which is parallel to the positive *y*-axis. In what direction will the magnetic force be acting on the electron?**
(*a*) Along $-x$ axis (*b*) Along $-z$ axis (*c*) Along $+z$ axis (*d*) Along $-y$ axis

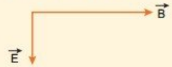
6. **The relative permeability of a substance *X* is slightly less than unity and that of substance *Y* is slightly more than unity, then**
(*a*) *X* is paramagnetic and *Y* is ferromagnetic
(*b*) *X* is diamagnetic and *Y* is ferromagnetic
(*c*) *X* and *Y* both are paramagnetic
(*d*) *X* is diamagnetic and *Y* is paramagnetic

7. **An ammeter of resistance 0.81 ohm reads up to 1 A. The value of the required shunt to increase the range to 10 A is**
(*a*) 0.9 ohm (*b*) 0.09 ohm (*c*) 0.03 ohm (*d*) 0.3 ohm

8. **An electron with angular momentum *L* moving around the nucleus has a magnetic moment given by**
(*a*) $eL/2m$ (*b*) $eL/3m$ (*c*) $eL/4m$ (*d*) eL/m

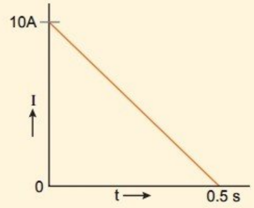
9. **The large scale transmission of electrical energy over long distances is done with the use of transformers. The voltage output of the generator is stepped-up because of**
(*a*) reduction of current (*b*) reduction of current and voltage both
(*c*) power loss is cut down (*d*) (*a*) and (*c*) both

10. **The diagram below shows the electric field ($\vec{E}$) and magnetic field ($\vec{B}$) components of an electromagnetic wave at a certain time and location.**



The direction of the propagation of the electromagnetic wave is
(*a*) perpendicular to $\vec{E}$ and $\vec{B}$ and out of plane of the paper
(*b*) perpendicular to $\vec{E}$ and $\vec{B}$ and into the plane of the paper
(*c*) parallel and in the same direction as $\vec{E}$
(*d*) parallel and in the same direction as $\vec{B}$

11. **In a coil of resistance 100 Ω a current is induced by changing the magnetic flux through it. The variation of current with time is as shown in the figure. The magnitude of change in flux through coil is**



(*a*) 200 Wb (*b*) 275 Wb (*c*) 225 Wb (*d*) 250 Wb

12. **The energy of an electron in n^{th} orbit of hydrogen atom is $E_n = -13.6/n^2$ eV. The negative sign of energy indicates that**
(*a*) electron is free to move.
(*b*) electron is bound to the nucleus.
(*c*) kinetic energy of electron is equal to potential energy of electron.
(*d*) atom is radiating energy.

For Questions 13 to 16, two statements are given – one labelled Assertion (A) and other labelled Reason (R). Select the correct answer to these questions from the options as given below.

(a) If both Assertion and Reason are true and Reason is correct explanation of Assertion.

(b) If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.

(c) If Assertion is true but Reason is false.

(d) If both Assertion and Reason are false.

13. **Assertion(*A*)** : For the radiation of a frequency greater than the threshold frequency, photoelectric current is proportional to the intensity of the radiation.

Reason (*R*) : Greater the number of energy quanta available, greater is the number of electrons absorbing the energy quanta and greater is number of electrons coming out of the metal.

14. **Assertion(*A*)** : Putting *p*-type semiconductor slab directly in physical contact with *n*-type semiconductor slab cannot form the *p-n* junction.

Reason (*R*) : The roughness at contact will be much more than inter atomic crystal spacing and continuous flow of charge carriers is not possible.

15. **Assertion(*A*)** : An electron has a higher potential energy when it is at a location associated with a negative value of potential and has a lower potential energy when at a location associated with a positive potential.

Reason (*R*) : Electrons move from a region of higher potential to a region of lower potential.

16. **Assertion(*A*)** : Propagation of light through an optical fibre is due to total internal reflection taking place at the core-cladding interface.

Reason (*R*) : Refractive index of the material of the cladding of the optical fibre is greater than that of the core.

SECTION–B

17. (*a*) Name the device which utilizes unilateral action of a *p-n* diode to convert *ac* into *dc*.

(*b*) Draw the circuit diagram of full wave rectifier.

18. The wavelength λ of a photon and the de Broglie wavelength of an electron of mass m have the same value. Show that the energy of the photon is $2\lambda mc/h$ times the kinetic energy of the electron, where c and h have their usual meanings.

19. A ray of monochromatic light passes through an equilateral glass prism in such a way that the angle of incidence is equal to the angle of emergence and each of these angles is 3/4 times the angle of the prism. Determine the angle of deviation and the refractive index of the glass prism.

20. A heating element using nichrome connected to a 230 V supply draws an initial current of 3.2 A which settles after a few seconds to a steady value of 2.8 A. What is the steady temperature of the heating element if the room temperature is 27.0 °C and the temperature coefficient of resistance of nichrome is $1.70 \times 10^{-4}\ °C^{-1}$?

21. Show that the least possible distance between an object and its real image in a convex lens is $4f$, where f is the focal length of the lens.

OR

In an astronomical telescope in normal adjustment a straight black line of length L is drawn on the objective lens. The eyepiece forms a real image of this line whose length is l. What is the angular magnification of the telescope?

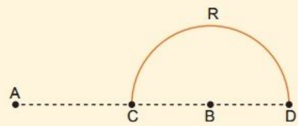
SECTION–C

22. A given coin has a mass of 3.0 g. Calculate the nuclear energy that would be required to separate all the neutrons and protons from each other. For simplicity assume that the coin is entirely made of $^{63}_{29}\text{Cu}$ atoms (of mass 62.92960 u). Given $m_p = 1.007825\text{u}$ and $m_n = 1.008665\text{u}$.

OR

Draw the graph showing the variation of binding energy per nucleon with mass number. Write two inferences which can be drawn from this graph.

23. Charges $(+q)$ and $(-q)$ are placed at the points A and B respectively which are a distance $2L$ apart. C is the midpoint between A and B. What is the work done in moving a charge $+Q$ along the semicircle CRD.



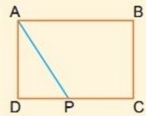
24. The total energy of an electron in the first excited state of the hydrogen atom is about –3.4 eV.

(*a*) What is the kinetic energy of the electron in this state?

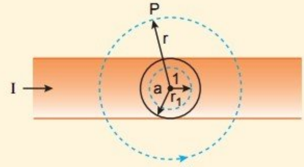
(*b*) What is the potential energy of the electron in this state?

(*c*) Which of the answers above would change if the choice of the zero of potential energy is changed?

25. A wire of uniform cross-section and resistance 4 ohm is bent in the shape of square $ABCD$. Point A is connected to a point P on DC by a wire AP of resistance 1 ohm. When a potential difference is applied between A and C, the points B and P are seen to be at the same potential. What is the resistance of the part DP?



26. The given figure shows a long straight wire of a circular cross-section (radius a) carrying steady current I. The current I is uniformly distributed across this cross-section. Calculate the magnetic field in the region $r < a$ and $r > a$.



27. Identify the part of the electromagnetic spectrum which:

(*a*) produces heating effect,

(*b*) is absorbed by the ozone layer in the atmosphere,

(*c*) is used for studying crystal structure.

Write any one method of the production of each of the above radiations.

28. (*a*) Define mutual inductance and write its SI unit.

(*b*) Two circular loops, one of small radius r and other of larger radius R, such that $R >> r$, are placed coaxially with centres coinciding. Obtain the mutual inductance of the arrangement.

OR

Two long straight parallel current carrying conductors are kept 'a' distant apart in air. The direction of current in both the conductors is same. Find the magnitude of force per unit length and direction of the force between them. Hence define one ampere.

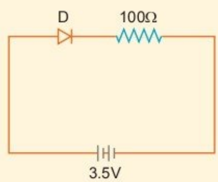
SECTION–D

Case Study Based Questions

29. **Read the following paragraph and answer the questions that follow.**

A semiconductor diode is basically a p-n junction with metallic contacts provided at the ends for the application of an external voltage. It is a two terminal device. When an external voltage is applied across a semiconductor diode such that p-side is connected to the positive terminal of the battery and n-side to the negative terminal, it is said to be forward biased. When an external voltage is applied across the diode such that n-side is positive and p-side is negative, it is said to be reverse biased. An ideal diode is one whose resistance in forward biasing is zero and the resistance is infinite in reverse biasing. When the diode is forward biased, it is found that beyond forward voltage called knee voltage, the conductivity is very high. When the biasing voltage is more than the knee voltage the potential barrier is overcome and the current increases rapidly with increase in forward voltage. When the diode is reverse biased, the reverse bias voltage produces a very small current about a few microamperes which almost remains constant with bias. This small current is reverse saturation current.

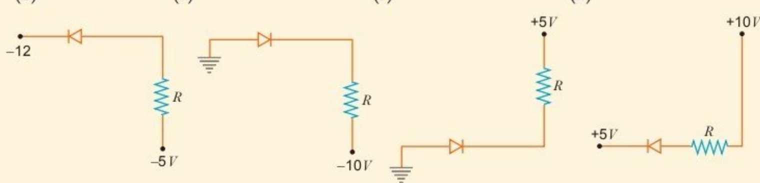
(*i*) In the given figure, a diode D is connected to an external resistance $R = 100\ \Omega$ and an emf of 3.5 V. If the barrier potential developed across the diode is 0.5 V, the current in the circuit will be



(*a*) 40 mA (*b*) 20 mA
(*c*) 35 mA (*d*) 30 mA

(*ii*) In which of the following figures, the p-n diode is reverse biased?

(*a*) (*b*) (*c*) (*d*)

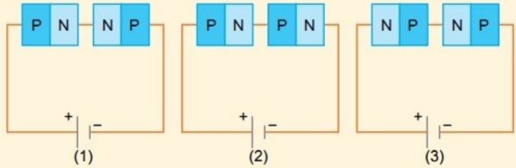


(*iii*) Based on the V-I characteristics of the diode, we can classify diode as

(*a*) bilateral device (*b*) ohmic device
(*c*) non-ohmic device (*d*) passive element

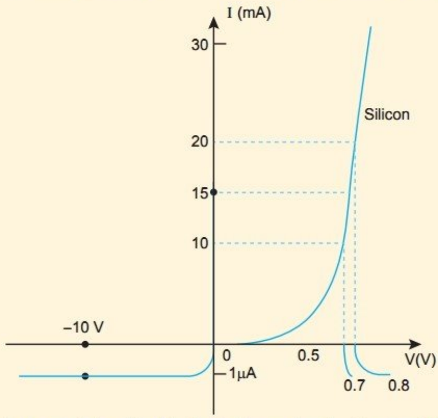
OR

Two identical *PN* junctions can be connected in series by three different methods as shown in the figure. If the potential difference in the junctions is the same, then the correct connections will be



(*a*) in the circuits (1) and (2)
(*b*) in the circuits (2) and (3)
(*c*) in the circuits (1) and (3)
(*d*) only in the circuit (1)

(*iv*)



The *V-I* characteristic of a diode is shown in the figure. The ratio of the resistance of the diode at $I = 15$ mA to the resistance at $V = -10$ V is

(*a*) 100 (*b*) 10^6 (*c*) 10 (*d*) 10^{-6}

30. Read the following paragraph and answer the questions that follow.

Types of Lenses and their combination

A convex or converging lens is thicker at the centre than at the edges. It converges a beam of light on refraction through it. It has a real focus. Convex lens is of three types: Double convex lens, Plano convex lens and Concavo-convex lens.

Concave lens is thinner at the centre than at the edges. It diverges a beam of light on refraction through it. It has a virtual focus. Concave lenses are of three types: Double concave lens, Plano concave lens and Convexo-concave lens.

When two thin lenses of focal lengths f_1 and f_2 are placed in contact with each other along their common principal axis, then the two lens system is regarded as a single lens of focal length f and

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

If several thin lenses of focal length $f_1, f_2, ... f_n$ are placed in contact, then the effective focal length of the combination is given by

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} + ... + \frac{1}{f_n}$$

and in terms of power, we can write

$$P = P_1 + P_2 + ... + P_n$$

The value of focal length and power of a lens must be used with proper sign consideration.

(*i*) Two thin lenses are kept coaxially in contact with each other and the focal length of the combination is 80 cm. If the focal length of one lens is 20 cm, the focal length of the other would be

(*a*) –26.7 cm (*b*) 60 cm (*c*) 80 cm (*d*) 30 cm

(*ii*) A spherical air bubble is embedded in a piece of glass. For a ray of light passing through the bubble, it behaves like a

(*a*) converging lens (*b*) diverging lens

(*c*) mirror (*d*) thin plane sheet of glass

(*iii*) Lens generally used in magnifying glass is

(*a*) single concave lens

(*b*) single convex lens

(*c*) combination of convex lens of lower power and concave lens of lower focal length

(*d*) Planoconcave lens

(*iv*) The magnification of an image by a convex lens is positive only when the object is placed

(*a*) at its focus F (*b*) between F and $2F$

(*c*) at $2F$ (*d*) between F and optical centre

OR

A convex lens of 20 cm focal length forms a real image which is three times magnified. The distance of the object from the lens is

(*a*) 13.33 cm (*b*) 14 cm (*c*) 26.66 cm (*d*) 25 cm

SECTION–E

31. (*i*) Draw a ray diagram for the formation of image of a point object by a thin double convex lens having radii of curvature R_1 and R_2. Hence derive lens maker's formula.

(*ii*) A converging lens has a focal length of 10 cm in air. It is made of a material of refractive index 1.6. If it is immersed in a liquid of refractive index 1.3, find its new focal length.

OR

(*i*) Define a wavefront. How is it different from a ray?

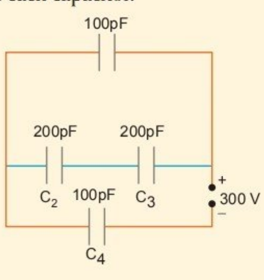
(*ii*) Using Huygens's construction of secondary wavelets draw a diagram showing the passage of a plane wavefront from a denser to a rarer medium. Using it verify Snell's law.

(*iii*) In a double slit experiment using light of wavelength 600 nm and the angular width of the fringe formed on a distant screen is 0.1°. Find the spacing between the two slits.

(*iv*) Write two differences between interference pattern and diffraction pattern.

32. (*i*) Derive an expression for the capacitance of a parallel plate capacitor with air present between the two plates.

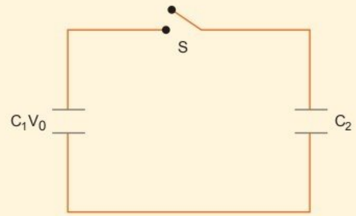
(*ii*) Obtain the equivalent capacitance of the network shown in figure. For a 300 V supply, determine the charge on each capacitor.



OR

(*i*) A dielectric slab of thickness 't' is kept between the plates of a parallel plate capacitor with plate separation 'd' ($t < d$). Derive the expression for the capacitance of the capacitor.

(*ii*) A capacitor of capacity C_1 is charged to the potential of V_0. On disconnecting with the battery, it is connected with an uncharged capacitor of capacity C_2 as shown in the adjoining figure. Find the ratio of energies before and after the connection of switch S.



33. (*i*) Draw graphs showing the variations of inductive reactance and capacitive reactance with frequency of applied *ac* source.

(*ii*) Draw the phasor diagram for a series RLC circuit connected to an AC source.

(*iii*) When an alternating voltage of 220V is applied across a device X, a current of 0.25A flows which lags behind the applied voltage in phase by $\pi/2$ radian. If the same voltage is applied across another device Y, the same current flows but now it is in phase with the applied voltage.

(*a*) Name the devices X and Y.

(*b*) Calculate the current flowing in the circuit when the same voltage is applied across the series combination of X and Y.

OR

(*i*) A series RLC circuit is connected to an *ac* source. Using the phasor diagram, derive the expression for the impedance of the circuit.

(*ii*) Plot a graph to show the variation of current with frequency of the *ac* source , explaining the nature of its variation for two different resistances R_1 and R_2 ($R_1 < R_2$) at resonance.

ANSWERS

SECTION–A

1. (*c*) In uniform electric field, equipotential surfaces are never concentric spheres but electric field lines always pass perpendicular to the planes of equipotential surface. 1

2. (*c*) Charge on dipole, $q = \tau/[(2a)E\sin\theta] = \dfrac{4}{2\times10^{-2}\times2\times10^{5}\sin30°}$

$$= 2\times10^{-3}\text{ C} = 2\text{ mC}$$ 1

3. (*d*) Higher the frequency, greater is the stopping potential. 1

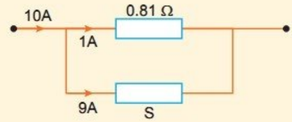
4. (*c*) Most of α-particles passes through the gold foil undeflected. This implies that most part of the atom is hollow. 1

5. (*b*) According to Fleming's left hand rules electron experience force in direction along –Z-axis. 1

6. (*d*) For diamagnetic material, $\mu_r < 1$ 1

For paramagnetic material, $\mu_r > 1$

7. (*b*) Required shunt resistance,



$$S = \frac{I_g R_g}{I - I_g}$$

$$= \frac{1 \times 0.81}{10 - 1} = \frac{0.81}{9} = 0.09\text{A}$$ 1

8. (*a*) Let e is the charge on an electron revolving in an orbit of radius r with uniform angular velocity ω, then

$$I = \frac{e}{T} = \frac{ev}{2\pi r}$$

Now, magnetic moment, $M = IA = \frac{ev}{2\pi r} \times \pi r^2 = \frac{evr}{2}$ $[A = \pi r^2]$

As from realtion, angular momenturm, $L = mvr$ 1

So, $M = \frac{eL}{2m}$

9. (*d*) For large scale transmission of electrical energy, the voltage output of the generator is stepped up because in this set up, current is reduced and consequently, the power (*i.e.*, i^2R) loss is cut down. 1

10. (*a*) EM waves are mutually perpendicular to $\vec{E}$ and $\vec{B}$.

So, $-\hat{j} \times \hat{i} = \hat{k}$

Hence, EM wave is perpendicular to $\vec{E}$ and $\vec{B}$ out of the plane of the paper. 1

11. (*d*) As we know, $e = \frac{\Delta\Phi}{\Delta t}$ and $I = \frac{1}{R}\frac{\Delta\Phi}{\Delta t}$

From graph, $I\,\Delta t = \frac{\Delta\Phi}{R}$ = Area under $I - t$ graph, $R = 100$ ohm

$\therefore$ $\Delta\Phi = R \times$ (Area under $I - t$ graph)

$$= 100 \times \frac{1}{2} \times 10 \times 0.5 = 250 \text{ Wb.}$$ 1

12. (*b*) As from relation, $E_n = -\frac{13.6}{n^2}$ eV

The negative sign of energy indicates that electrostatic force is attractive in nature that's why electron is bound to the nucleus. 1

13. (*a*) Both Assertion (*A*) and Reason (*R*) are true and Reason (*R*) is correct explanation of Assertion (*A*). 1

14. (*a*) Both Assertion (*A*) and Reason (*R*) are true and Reason (*R*) is correct explanation of Assertion (*A*). 1

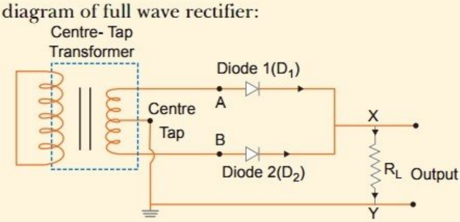
15. (*c*) Electron is a negative charge particle so, it moves from a region of lower potential to a region of higher potential. 1

16. (*c*) Refraction index of the material of the cladding of the optical fiber is greater than that of the core. 1

SECTION–B

17. (*a*) Rectifier.

(*b*) Circuit diagram of full wave rectifier: 1



1

18. Energy of photon, $E_P = \dfrac{hc}{\lambda}$ ½

For proton, $\lambda = \dfrac{h}{mv}$

$\therefore$ $mv = \dfrac{h}{\lambda}$

Kinetic energy of proton, $E_k = \dfrac{1}{2}mv^2$ ½

$$E_k = \frac{1}{2}\frac{h^2}{m\lambda^2}$$ ½

$\therefore$ $E_P = \left(\dfrac{2m\lambda c}{h}\right)E_k$ ½

19. Here, angle of prism $A = 60°$,

Angle of incidence (i) = angle of emergence (e)

$\therefore \quad i = e = \dfrac{3}{4}A = \dfrac{3}{4}\times 60° = 45°$ and $i + e = A + \delta$ 1

As per given condition angle of deviation is minimum.

$\therefore \ \delta_m = 2i - A = 2\times 45° - 60° = 30°$

$\therefore$ Refractive index of glass prism,

$$n = \frac{\sin\left(\dfrac{A+\delta_m}{2}\right)}{\sin\left(\dfrac{A}{2}\right)} = \frac{\dfrac{\sin(60° + 30°)}{2}}{\sin\left(\dfrac{60°}{2}\right)} = \frac{\sin 45°}{\sin 30°} = \frac{\dfrac{1}{\sqrt{2}}}{\dfrac{1}{2}} = \sqrt{2}.$$ 1

20. Given, $V = 230$ V, $I_0 = 3.2$ A, $I = 2.8$ A, $T_0 = 27°$ C, $\alpha = 1.70 \times 10^{-4}$ °C^{-1}.

Using equation, $R = R_0\,(1 + \alpha\Delta T)$ ½

$\Rightarrow$ $V/I = V/\,I_0\}\ [1 + \alpha\,\Delta T]$

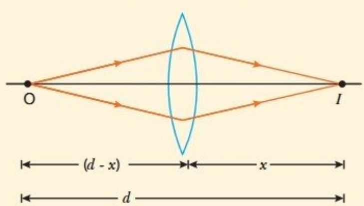
$\Rightarrow$ $\dfrac{I_0}{I} = (1 + \alpha\Delta T)$

$\Rightarrow$ $\alpha\Delta T = \dfrac{I_0}{I} - 1 = \dfrac{3.2}{2.8} - 1 = 1.14$

$\therefore$ $\Delta T = \dfrac{1.14}{1.70}\times 10^4 = 840$ ½

Hence, $T = \Delta T + T = 840 + 27 = 867$°C 1

21. Let d be the least distance between object and image for a real image formation.



½

Using Lens formula,

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \quad \Rightarrow \quad \frac{1}{f} = \frac{1}{x} + \frac{1}{d-x} = \frac{d}{x(d-x)} \qquad \frac{1}{2}$$

$$\Rightarrow \qquad fd = xd - x^2$$

$$\Rightarrow \qquad x^2 - dx + fd = 0 \quad \Rightarrow \quad x = \frac{d \pm \sqrt{d^2 - 4fd}}{2} \qquad \frac{1}{2}$$

For real roots of x, $d^2 - 4fd \geq 0$

Hence, $\qquad d \geq 4f.$ ½

OR

Let f_o and f_e be the focal length of the objective and eyepiece respectively.

For normal adjustment, the distance from objective to eyepiece, $L = f_o + f_e$

Taking the line on the objective as object and eyepiece as lens,

$$u = -(f_o + f_e) \quad \text{and} \quad f = f_e \qquad 1$$

Using Lens formula,

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

$$\Rightarrow \qquad \frac{1}{v} - \frac{1}{[-(f_o + f_e)]} = \frac{1}{f_e} \qquad \Rightarrow v = \left(\frac{f_o + f_e}{f_o}\right) f_e$$

Now,

Linear magnification (eyepiece) $= \dfrac{v}{u} = \dfrac{\text{Image size}}{\text{Object size}} = \dfrac{f_e}{f_o} = \dfrac{l}{L}$ ½

$\therefore$ Angular magnification of telescope,

$$M = \frac{f_o}{f_e} = \frac{L}{l} \qquad \frac{1}{2}$$

SECTION–C

22. Number of atoms in 3 gram of Cu coin $= \dfrac{(6.023 \times 10^{23} \times 3)}{63} = 2.86 \times 10^{22}$ ½

For Cu atom, number of protons = 29 and number of neutrons = 34

Now, Mass defect, $\Delta_m = 29 \times 1.00783 + 34 \times 1.00867 - 62.92960 \text{ u} = 0.59225 \text{ u}$ 1

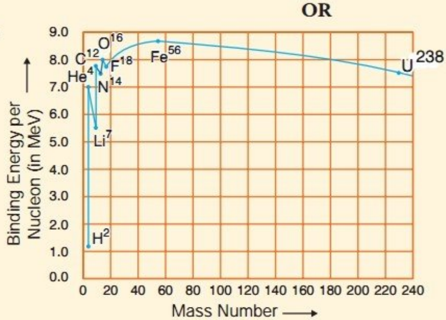
Nuclear energy required for one atom = 0.59225×931.5 MeV ½

$\therefore$ Nuclear energy required for 3 gram of Cu = $0.59225 \times 931.5 \times 2.86 \times 10^{22}$ MeV 1

$= 1.58 \times 10^{25}$ MeV

OR

Graph:



2

(*i*) The binding energy per nucleon, E_{bn}, is practically constant, *i.e.*, practically independent of the atomic number for nuclei of middle mass number ($30 < A < 170$). The curve has a maximum of about 8.75 MeV for $A = 56$ and has a value of 7.6 MeV for $A = 238$.

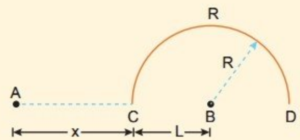
(*ii*) E_{bn} is lower for both light nuclei ($A < 30$) and heavy nuclei ($A > 170$).

We can draw some conclusions from these two observations:

(*i*) The force is attractive and sufficiently strong to produce a binding energy of a few MeV per nucleon. **1**

(*ii*) The constancy of the binding energy in the range $30 < A < 170$ is a consequence of the fact that the nuclear force is short-ranged.

23. Here, $R = L,\ q_A = +q,\ q_B = -q$



Potential at $C, V_C = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{L} + \dfrac{1}{4\pi\varepsilon_0}\left(\dfrac{-q}{L}\right) = 0$ **1**

Potential at $D, V_D = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{3L} + \dfrac{1}{4\pi\varepsilon_0}\left(\dfrac{-q}{L}\right) = \dfrac{-q}{6\pi\varepsilon_0 L}$ **1**

We know that, Work done, $W = Q[V_D - V_C]$

$$= Q\left[\frac{-q}{6\pi\varepsilon_0 L} - 0\right] = \frac{-Qq}{6\pi\varepsilon_0 L}$$ **1**

24. As we know, Kinetic energy, $K = -E$ and Potential energy, $U = -2K$

(*a*) Kinetic energy, $K = -E = -(-3.4) = 3.4$ eV **1**

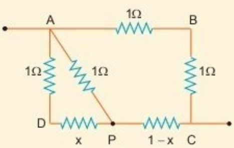
(*b*) Potential energy, $U = -2K = -2 \times 3.4 = -6.8$ eV **1**

(*c*) The kinetic energy of the electron will not change. The value of potential energy and consequently, the value of total energy of the electron will change. **1**

25. As from given, resistance of each side, $R = 1\Omega$

Let the resistance of *DP* part is *x* ohm.

As from circuit shown,



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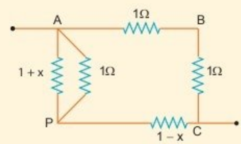
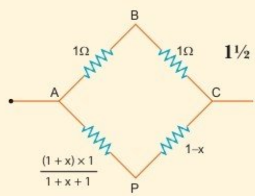




1½

Two parallel resistance between *AP*,

$$R_1 = \frac{(1+x)(1)}{(1+x+1)} = \frac{x+1}{x+2}\,\Omega$$

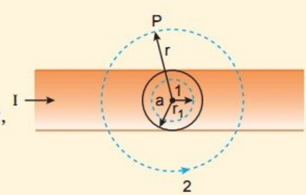
As the points *B* and *P* are at the same potential,

$$\frac{1}{1} = \frac{\dfrac{1+x}{2+x}}{1-x} \Rightarrow (1-x)(2+x) = 1+x$$ **1½**

$$\Rightarrow \qquad x^2 + 2x - 1 = 0$$

From solving this equation, we get

$$x = (\sqrt{2} - 1)\,\Omega$$



26. (*a*) Consider the case $r > a$. The Amperian loop, labelled 2, is a circle concentric with the cross-section.

For this loop, $L = 2\pi r$

Using Ampere's circuital Law, we can write,

$$B(2\pi r) = \mu_0 I, \quad B = \frac{\mu_0 I}{2\pi r}, \qquad 1\tfrac{1}{2}$$

i.e., $$B \propto \frac{1}{r} \qquad (r > a)$$

(*b*) Consider the case $r < a$. The Amperian loop is a circle labelled 1. For this loop, taking the radius of the circle to be r, $L = 2\pi r$

Now the current enclosed I_e is not I, but is less than this value. Since the current distribution is uniform, the current enclosed is,

$$I_e = I\left(\frac{\pi r^2}{\pi a^2}\right) = \frac{Ir^2}{a^2}$$

Using Ampere's circuital law, $B\ (2\pi r) = \mu_0 \dfrac{Ir^2}{a^2} \Rightarrow B = \left(\dfrac{\mu_0 I}{2\pi a^2}\right)r$ 1½

i.e., $B \propto r \qquad (r < a)$

27. (*a*) Infrared

(*b*) Ultraviolet

(*c*) X-rays 1½

Methods from production of above radiation:

(*a*) Infrared ray can be produced by vibrations of atoms and molecule.

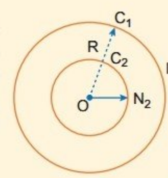
(*b*) UV radiation is produced by heating a body to an incandescent temperature, as is the case with solar UV, or by passing an electric current through a gass usually vaporized mercury.

(*c*) *X*-rays produced, when electrons are accelerated under a potential difference. 1½

28. (*a*) When current flowing in one of two nearby coils is changed, the magnetic flux linked with the other coil changes; due to which an emf is induced in it (other coil). This phenomenon of electromagnetic induction is called the **mutual induction**. The coil, in which current is changed is called the primary coil and the coil in which emf is induced is called the secondary coil. ½ + ½

The SI unit of mutual inductance is henry.

(*b*) **Mutual Inductance of two plane coils:** Consider two concentric circular plane coils C_1 and C_2 placed very near to each other. The number of turns in the primary coil is N_1 and radius is R_1 while the number of turns in the secondary coil is N_2 and its radius is R_2. If I_1 is the current in the primary coil, then magnetic field produced at its centre,



$$B_1 = \frac{\mu_0 N_1 I_1}{2R} \qquad ½$$

If we suppose this magnetic field to be uniform over the entire plane of secondary coil, then total *effective magnetic flux linkage* with secondary coil ½

$$\phi_0 = N_2 B_1 A_2 = N_2\left(\frac{\mu_0 N_1 I_1}{2R}\right)A_2 = \frac{\mu_0 N_1 N_2 A_2}{2R} I_1$$

By definition, Mutual Inductance, $M = \dfrac{\phi_2}{I_1} = \dfrac{\mu_0 N_1 N_2 A_2}{2R}$ ½

But $\quad A_2 = \pi r^2$

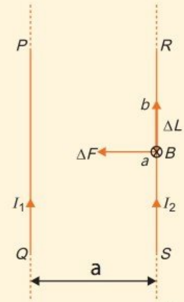
$\therefore \qquad M = \dfrac{\mu_0 N_1 N_2 \pi r^2}{2R}$

If both coils have one turn each; then $N_1 = N_2 = 1$,

So, mutual inductance, $M = \dfrac{\mu_0 \pi r^2}{2R}$ ½

OR

Suppose two long thin straight conductors (or wires) PQ and RS are placed parallel to each other in vacuum (or air) carrying currents I_1 and I_2 respectively. It has been observed experimentally that when the currents in the wire are in the same direction, they experience an attractive force (fig. a) and when they carry currents in opposite directions, they experience a repulsive force (fig. b).



Let the conductors PQ and RS carry currents I_1 and I_2 in same direction and placed at separation a.

Consider a current–element 'ab' of length ΔL of wire RS. The magnetic field produced by current-carrying conductor PQ at the location of other wire RS. ½

$$B_1 = \frac{\mu_0 I_1}{2\pi a} \qquad \ldots(i)$$

According to Maxwell's right hand rule or right hand palm rule number 1, the direction of B_1 will be perpendicular to the plane of paper and directed downward. Due to this magnetic field, each element of other wire experiences a force. The direction of current element is perpendicular to the magnetic field; therefore the magnetic force on element ab of length ΔL

$$\Delta F = B_1 I_2 \,\Delta L \sin 90^\circ = \frac{\mu_0 I_1}{2\pi a} I_2 \Delta L \qquad ½$$

$\therefore$ The total force on conductor of length L will be

$$F = \frac{\mu_0 I_1 I_2}{2\pi a} \Sigma \Delta L = \frac{\mu_0 I_1 I_2}{2\pi a} L \qquad ½$$

$\therefore$ Force acting per unit length of conductor

$$f = \frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi a} \text{ N/m} \qquad ½$$

According to Fleming's left hand rule, the direction of magnetic force will be towards PQ *i.e.*, the force will be attractive.

Definition of SI unit of Current (ampere): In SI system of fundamental unit of current 'ampere' is defined assuming the force between the two current carrying wires as standard.

The force between two parallel current carrying conductors of separation a is

$$f = \frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi a} \text{ N/m}$$

If $I_1 = I_2 = 1$ A, $a = 1$ m, then

$$f = \frac{\mu_0}{2\pi} = 2 \times 10^{-7} \text{ N/m} \qquad 1$$

Thus 1 ampere is the current which when flowing in each of parallel conductors placed at separation 1 m in vacuum exert a force of 2×10^{-7} on 1 m length of either wire.

SECTION–D

29. (*i*) (*d*) Here, $V = 3.5$ V, $V_b = 0.5$ V, $R = 100\,\Omega$

The diode connect in forward bias, so it allow the current through it with some barrier potential.

$\therefore$ Current, $$I = \frac{V - V_b}{R} = \frac{3.5 - 0.5}{100} = \frac{3}{100} = 30\text{ mA}$$

(*ii*) (*c*) n-side connected with higher potential than p-side of p-n junction diode. So it indicates that p-n diode in reverse biased. **1**

(*iii*) (*c*) A diode provides nearly constant voltage drop even if you vary the current, so it does not follow Ohm's Law. **1**

OR

(*b*) In circuit (2) both the diodes are forward biased and in circuit (3) both the diodes are reversed biased. Therefore, circuit (2) and (3) have equal potential drop.

(*iv*) (*d*) From V–I characterstics curve,

At $I = 15$ mA, $V = 0.75$ V

$$\therefore \quad R_1 = \frac{V}{I} = \frac{0.75}{15\times10^{-3}} = 50\,\Omega$$

At $V = -10$ V, $I = -10^{-6}$ A.

$$\therefore \quad R_2 = \frac{V}{I} = \frac{-10}{-10^{-6}} = 10^7\text{A}$$

So, Ratio, $$\frac{R_1}{R_2} = \frac{50}{10^7} = 5\times10^{-6}$$ **1**

30. (*i*) (*a*) For combination of lenses,

$$\frac{1}{f_{eq}} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$\Rightarrow \quad \frac{1}{f_2} = \frac{1}{f_{eq}} - \frac{1}{f_1} = \frac{1}{80} - \frac{1}{20} = \frac{1-4}{80} = \frac{-3}{80}$$ **1**

$$\therefore \quad f_2 = \frac{-80}{3} = -26.7\text{ cm.}$$

(*ii*) (*b*) A spherical air bubble is embedded in a piece of glass as look like similar as plano-concave lens. Hence it behave as diverging lens. **1**

(*iii*) (*b*) A single convex lens is generally used as magnifying glass. **1**

(*iv*) (*d*) For $m = +$ve (means image is virtual and erect) **1**

So, for convex lens, it possible only when object is place between F and O.

OR

(*c*) Here, $f = 20$ cm, $m = -3$ [Real image]

Now, $m = \frac{v}{u} \Rightarrow v = -3u$

Using Lens formula,

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\Rightarrow \quad \frac{1}{20} = \frac{1}{(-3u)} - \frac{1}{4} = \frac{-1-3}{3u} = \frac{-4}{3u}$$

$$\Rightarrow \quad 3u = -80$$

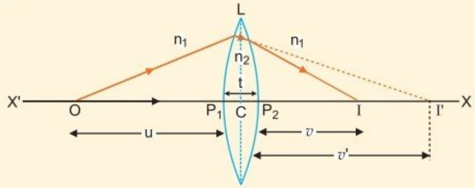
$$\therefore \quad u = \frac{-80}{30} = -26.66\text{ cm.}$$

Negative sign shows that object is placed at left side of lens from optical centre.

SECTION–E

31. (*i*) **Lens Maker's Formula:** Suppose L is a thin lens. The refractive index of the material of lens is n_2 and it is placed in a medium of refractive index n_1. The optical centre of lens is C and $X'X$ is the principal axis. The radii of curvature of the surfaces of the lens are R_1 and R_2 and their poles are P_1 and P_2 The thickness of lens is t, which is very small. O is a point object on the principal axis of the lens. The distance of O from pole P_1 is u. The first refracting surface forms the image of O at I' at a distance v' from P_1. From the refraction formula at spherical surface

½



$$\frac{n_2}{v'} - \frac{n_1}{u} = \frac{n_2 - n_1}{R_1} \qquad ...(i)$$

The image I' acts as a virtual object for second surface and after refraction at second surface, the final image is formed at I. The distance of I from pole P_2 of second surface is v. The distance of virtual object (I') from pole P_2 is $(v' - t)$.

For refraction at second surface, the ray is going from second medium (refractive index n_2) to first medium (refractive index n_1), therefore from refraction formula at spherical surface

$$\frac{n_1}{v} - \frac{n_2}{(v'-t)} = \frac{n_1 - n_2}{R_2} \qquad ...(ii)$$

For a thin lens t is negligible as compared to v' therefore from (*ii*)

$$\frac{n_1}{v} - \frac{n_2}{v'} = -\frac{n_2 - n_1}{R_2} \qquad ...(iii)$$

Adding equations (*i*) and (*iii*), we get

$$\frac{n_1}{v} - \frac{n_1}{u} = (n_2 - n_1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad ½$$

or
$$\frac{1}{v} - \frac{1}{u} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

i.e.
$$\frac{1}{v} - \frac{1}{u} = ({}_1n_2 - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad ...(iv)$$

where ${}_1n_2 = \frac{n_2}{n_1}$ is refractive index of second medium (*i.e.*, medium of lens) with respect to first medium.

If the object O is at infinity, the image will be formed at second focus *i.e.*, ½

if $u = \infty$, $v = f_2 = f$

Therefore from equation (*iv*)

$$\frac{1}{f} - \frac{1}{\infty} = ({}_1n_2 - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

i.e.,
$$\boldsymbol{\frac{1}{f} = ({}_1n_2 - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)} \qquad ½$$

This formula is called ***Lens-Maker's formula.***

If first medium is air and refractive index of material of lens be n, then ${}_1n_2 = n$, therefore the modified equation *(v)* may be written as

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

(*ii*) From above relation,

For air, $$\frac{1}{f_a} = (1.6-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right) \quad ...(i)$$

And, for Liquid, $$\frac{1}{f_l} = \left[\frac{1.6}{1.3}-1\right]\left(\frac{1}{R_1}-\frac{1}{R_2}\right) \quad ...(ii) \quad \mathbf{1}$$

From equation (*i*) and (*ii*),

$$\frac{f_l}{f_a} = \left[\frac{0.6}{0.3}\times 1.3\right]$$

$\Rightarrow$ $$f_l = 2.6 \times 10 \text{ cm}$$

$\therefore$ $$f_l = 26 \text{ cm} \quad \mathbf{1}$$

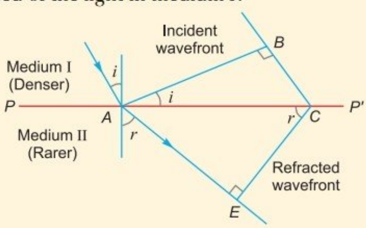
OR

(*i*) A wavefront is defined as a locus of all particles of medium vibrating in the same phase.

(*a*) The ray indicates the direction of propagation of wave while the wavefront is the surface of constant phase. **1**

(*b*) The ray at each point of a wavefront is normal to the wavefront at that point.

(*ii*) We assume a plane wavefront AB propagating in denser medium incident on the interface PP' at angle i as shown in Fig. Let t be the time taken by the wave front to travel a distance BC. If v_1 is the speed of the light in medium I.



So, $BC = v_1 t$

In order to find the shape of the refracted wavefront, we draw a sphere of radius $AE = v_2 t$, where v_2 is the speed of light in medium II (rarer medium). The tangent plane CE represents the refracted wavefront.

In ΔABC, $$\sin i = \frac{BC}{AC} = \frac{v_1 t}{AC}$$

and in ΔACE, $$\sin r = \frac{AE}{AC} = \frac{v_2 t}{AC}$$

$\therefore$ $$\frac{\sin i}{\sin r} = \frac{BC}{AE} = \frac{v_1 t}{v_2 t} = \frac{v_1}{v_2} \quad ...(i)$$

Let c be the speed of light in vacuum

So, $$n_1 = n_1 = \frac{c}{v_1} \text{ and } n_2 = \frac{c}{v_2}$$

$$\frac{n_2}{n_1} = \frac{v_1}{v_2} \quad \ldots(ii)$$

From equations (*i*) and (*ii*), we have

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1} \quad 2$$

or $$n_1 \sin i = n_2 \sin r$$

It is known as Snell's law.

(*iii*) For small angle θ, Sin θ ≃ θ,

Angular width,

$$\theta = \frac{\lambda}{a}$$

$$\therefore \quad a = \frac{\lambda}{\theta} = \frac{6\times10^{-7}}{0.1\times\frac{\pi}{180}} = 3.4\times10^{-4}\,\text{m} \quad 1$$

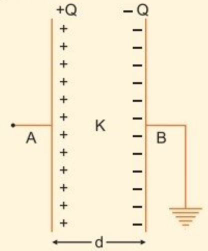
(*iv*) **Differences between interference and diffraction** 1

Interference	Diffraction
(*a*) It is due to the superposition of two waves coming from two coherent sources.	(*a*) It is due to the superposition of secondary wavelets originating from different parts of the same wavefront.
(*b*) The width of the interference bands is equal.	(*b*) The width of the diffraction bands is not the same.
(*c*) The intensity of all maxima (fringes) is same.	(*c*) The intensity of central maximum is maximum and goes on decreasing rapidly with increase in order of maxima.

(*Any two*)

32. (*i*) **Principle of a Capacitor:** A capacitor works on the principle that the capacitance of a conductor increases appreciably when an earthed conductor is brought near it.

Parallel Plate Capacitor: Consider a parallel plate capacitor having two plane metallic plates *A* and *B*, placed parallel to each other (see fig.). The plates carry equal and opposite charges $+Q$ and $-Q$ respectively.



In general, the electric field between the plates due to charges $+Q$ and $-Q$ remains uniform, but at the edges, the electric field lines deviate outward. If the separation between the plates is much smaller than the size of plates, the electric field strength between the plates may be assumed uniform.

Let *A* be the area of each plate, '*d*' the separation between the plates, K the dielectric constant of medium between the plates. If σ is the magnitude of charge density of plates, then

$$\sigma = \frac{Q}{A}$$

The electric field strength between the plates

$E = \frac{\sigma}{K\varepsilon_0}$ where ε_0 = permittivity of free space.

The potential difference between the plates, $V_{AB} = Ed = \frac{\sigma d}{K\varepsilon_0}$

Putting the value of σ and for air, $K = 1$ we get

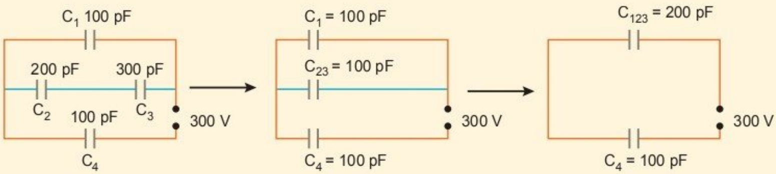
$$V_{AB} = \frac{(Q/A)d}{\varepsilon_0} = \frac{Qd}{\varepsilon_0 A}$$

$\therefore$ Capacitance of capacitor,

$$C = \frac{Q}{V_{AB}} = \frac{Q}{(Qd/\varepsilon_0 A)}$$

or $$C = \frac{\varepsilon_0 A}{d}$$ **2**

(*ii*) As from circuit shown,



1

Here C_2 and C_3 in series,

$$\therefore \quad C_{23} = \frac{C_2}{2} = \frac{200}{2} = 100 \text{ pF} \qquad [\text{Where } C_2 = C_3 = 200 \text{ pF}]$$

Again, C_1 and C_{23} in Parallel.

Then, $C_{123} = C_1 + C_{23} = 100 + 100 = 200$ pF

The equivalent capacitance, $C_{eq} = \dfrac{200 \times 100}{(200 + 100)} = \dfrac{200}{3}$ pF **½**

Now, Charge on C_4, $Q_4 = C_4 V = \dfrac{200}{3} \times 10^{-12} \times 300 = 2 \times 10^{-8}$ C

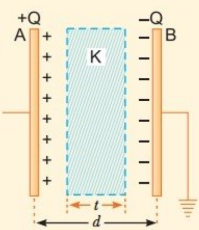
Potential difference across C_4, $V_4 = \dfrac{200 \times 10^{-12} \times 300}{3 \times 100 \times 10^{-12}} = 200$ V **½**

Potential difference across C_1, $V_1 = 300 - 200 = 100$ V
Then, Charge on C_1, $Q_1 = 100 \times 10^{-12} \times 100 = 1 \times 10^{-8}$ C
Potential difference across C_2 and C_3 in series combination = 100 V
Potential difference across C_2 and C_3 each = $\dfrac{100}{2}$ = 50V **½ + ½**

Charge on C_2 and C_3, $Q_2 = Q_3 = 200 \times 10^{-12} \times 50 = 1 \times 10^{-8}$ C

OR

(*i*) Consider a parallel plate capacitor, area of each plate being A, the separation between the plates being d. Let a dielectric slab of dielectric constant K and thickness $t < d$ be placed between the plates. The thickness of air between the plates is $(d - t)$. If charges on plates are $+Q$ and $-Q$, then surface charge density $\sigma = \dfrac{Q}{A}$



The electric field between the plates in air, $E_1 = \dfrac{\sigma}{\varepsilon_0} = \dfrac{Q}{\varepsilon_0 A}$

The electric field between the plates in slab, $E_2 = \dfrac{\sigma}{K\varepsilon_0} = \dfrac{Q}{K\varepsilon_0 A}$

$\therefore$ The potential difference between the plates

V_{AB} = work done in carrying unit positive charge from one plate to another
= ΣEx (as field between the plates is not constant).

$$= E_1(d-t) + E_2 t = \frac{Q}{\varepsilon_0 A}(d-t) + \frac{Q}{K\varepsilon_0 A}t$$

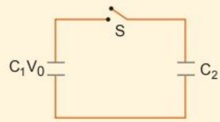
$\therefore$ $$V_{AB} = \frac{Q}{\varepsilon_0 A}\left[d - t + \frac{t}{K}\right]$$

$\therefore$ Capacitance of capacitor, $$C = \frac{Q}{V_{AB}} = \frac{Q}{\frac{Q}{\varepsilon_0 A}\left(d - t + \frac{t}{K}\right)}$$ **3**

or, $$C = \frac{\varepsilon_0 A}{d - t + \frac{t}{K}} = \frac{\varepsilon_0 A}{d - t\left(1 - \frac{1}{K}\right)}$$

(*ii*) Before the connection of switch S,

Initial energy $U_i = \frac{1}{2}C_1 V_0^2 + 0 = \frac{1}{2}C_1 V_0^2$



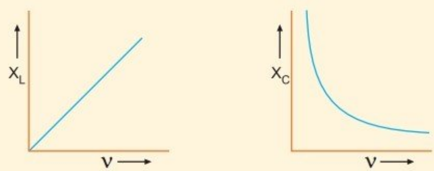
After the connection of switch S **½**

Common potential, $V = \dfrac{C_1V_1 + C_2V_2}{C_1 + C_2} = \dfrac{C_1V_0}{C_1 + C_2}$ **½**

Final energy, $U_f = \dfrac{1}{2}(C_1 + C_2)\dfrac{(C_1V_0)^2}{(C_1 + C_2)^2} = \dfrac{1}{2}\dfrac{C_1^2 V_0^2}{(C_1 + C_2)}$ **½**

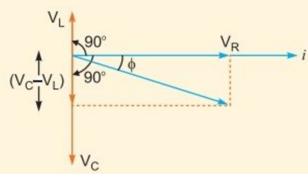
Hence, Ratio, $U_f : U_i = \dfrac{C_1}{(C_1 + C_2)}$ **½**

33. (*i*) Graph:



(a) (b) **½ + ½**

(*ii*) Phasor diagram:



1

(*iii*) (*a*) In device X, Current lags behind the voltage by $\pi/2$, hence X is an inductor.

In device Y, Current in phase with the applied voltage, hence, Y is resistor. **½ + ½**

(*b*) We are given that, $I = 0.25$ A

$X_L = \dfrac{V}{I} = \dfrac{220}{0.25} = 880\Omega$, Also $R = \dfrac{V}{I} = \dfrac{220}{0.25} = 880\Omega$ **1**

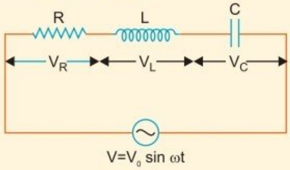
For the series combination of X and Y,

Equivalent impedance, $Z = \sqrt{R^2 + X_L^2} = \sqrt{(880)^2 + (880)^2} = 880\sqrt{2}\,\Omega$

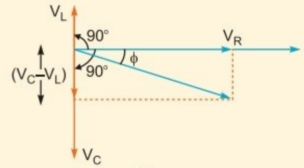
$$\therefore \text{ current,} \quad I = \frac{V}{Z} = \frac{220}{880\sqrt{2}} = 0.177 \text{ A}$$ 1

OR

(*i*) **Expression for Impedance in *LCR* series circuit:** Suppose resistance R, inductance L and capacitance C are connected in series and an alternating source of voltage $V = V_0 \sin \omega t$ is applied across it (fig. a). On account of being in series, the current (i) flowing through all of them is the same. 1



(a)



(b)

Suppose the voltage across resistance R is V_R voltage across inductance L is V_L and voltage across capacitance C is V_C. The voltage V_R and current i are in the same phase, the voltage V_L will lead the current by angle 90° while the voltage V_C will lag behind the current by angle 90° (fig. *b*). Clearly V_C and V_L are in opposite directions, therefore their resultant potential difference $= V_C - V_L$ (if $V_C > V_L$).

Thus V_R and $(V_C - V_L)$ are mutually perpendicular and the phase difference between them is 90°. As applied voltage across the circuit is V, the resultant of V_R and $(V_C - V_L)$ will also be V. From fig.

$$V^2 = V_R^2 + (V_C - V_L)^2 \quad \Rightarrow \quad V = \sqrt{V_R^2 + (V_C - V_L)^2} \qquad \text{...}(i)$$

But $V_R = R\,i$, $V_C = X_C\,i$ and $V_L = X_L\,i$ ...(*ii*)

where $X_C = \dfrac{1}{\omega C}$ = capacitance reactance and $X_L = \omega L$ = inductive reactance

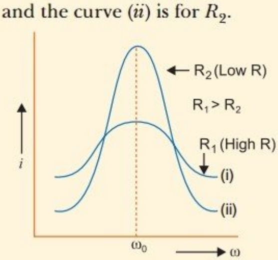
$$V = \sqrt{(Ri)^2 + (X_C i - X_L i)^2}$$

Impedance of circuit, $Z = \dfrac{V}{i} = \sqrt{R^2 + (X_C - X_L)^2}$

$$= \sqrt{R^2 + \left(\frac{1}{\omega C} - \omega L\right)^2}$$ 3

The phase difference (ϕ) between current and voltage is given by, $\tan \phi = \dfrac{X_C - X_L}{R}$

(*ii*) The curve (*i*) is for R_1 and the curve (*ii*) is for R_2. 1



CBSE Sample Question Paper–2023 (Unsolved)

Time allowed: 3 minutes **Maximum marks: 70**

General Instructions:

(i) *There are 35 questions in all. All questions are compulsory.*

(ii) *This question paper has five sections: Section A, Section B, Section C, Section D and Section E. All the sections are compulsory.*

(iii) *Section A contains eighteen MCQs of 1 mark each, Section B contains seven questions of two marks each, Section C contains five questions of three marks each, section D contains three long questions of five marks each and Section E contains two case study based questions of 4 marks each.*

(iv) *There is no overall choice. However, an internal choice has been provided in section B, C, D and E. You have to attempt only one of the choices in such questions.*

(v) *Use of calculators is not allowed.*

SECTION–A

Choose and write the correct option in the following questions.

1. According to Coulomb's law, which is the correct relation for the following figure?

(*a*) $q_1 q_2 > 0$

(*b*) $q_1 q_2 < 0$

(*c*) $q_1 q_2 = 0$

(*d*) $1 > \frac{q_1}{q_2} > 0$

2. The electric potential on the axis of an electric dipole at a distance '*r* from it's centre is *V*. Then the potential at a point at the same distance on its equatorial line will be

(*a*) $2V$

(*b*) $-V$

(*c*) $\frac{V}{2}$

(*d*) zero

3. The temperature (*T*) dependence of resistivity of material *A* and material *B* is represented by fig (*i*) and fig (*ii*) respectively. Identify material *A* and material *B*.

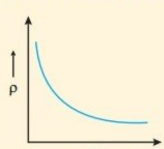


Fig (i)

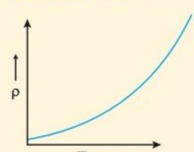


Fig (ii)

(*a*) Material *A* is copper and material *B* is germanium

(*b*) Material *A* is germanium and material *B* is copper

(*c*) Material *A* is nichrome and material *B* is germanium

(*d*) Material *A* is copper and material *B* is nichrome

4. **Two concentric and coplanar circular loops P and Q have their radii in the ratio 2:3. Loop Q carries a current 9 A in the anticlockwise direction. For the magnetic field to be zero at the common centre, loop P must carry**

(*a*) 3 A in clockwise direction
(*b*) 9 A in clockwise direction
(*c*) 6 A in anti-clockwise direction
(*d*) 6 A in the clockwise direction

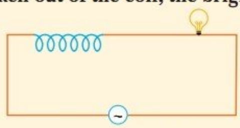
5. **A long straight wire of circular cross section of radius a carries a steady current I. The current is uniformly distributed across its cross section. The ratio of the magnitudes of magnetic field at a point distant $\frac{a}{2}$ above the surface of wire to that at a point distant $\frac{a}{2}$ below its surface is**

(*a*) 4 : 1
(*b*) 1 : 1
(*c*) 4 : 3
(*d*) 3 : 4

6. **If the magnetizing field on a ferromagnetic material is increased, its permeability**

(*a*) decreases
(*b*) increases
(*c*) remains unchanged
(*d*) first decreases and then increases

7. **An iron cored coil is connected in series with an electric bulb with an AC source as shown in figure. When iron piece is taken out of the coil, the brightness of the bulb will**



(*a*) decrease
(*b*) increase
(*c*) remain unaffected
(*d*) fluctuate

8. **Which of the following statement is NOT true about the properties of electromagnetic waves?**

(*a*) These waves do not require any material medium for their propagation.
(*b*) Both electric and magnetic field vectors attain the maxima and minima at the same time.
(*c*) The energy in electromagnetic wave is divided equally between electric and magnetic fields.
(*d*) Both electric and magnetic field vectors are parallel to each other.

9. **A rectangular, a square, a circular and an elliptical loop, all in the $(x - y)$ plane, are moving out of a uniform magnetic field with a constant velocity $\vec{v} = v\hat{i}$. The magnetic field is directed along the negative z-axis direction. The induced emf, during the passage of these loops, out of the field region, will not remain constant for**

(*a*) any of the four loops
(*b*) the circular and elliptical loops
(*c*) the rectangular, circular and elliptical loops
(*d*) only the elliptical loops

10. **In a Young's double slit experiment, the path difference at a certain point on the screen between two interfering waves is $\frac{1}{8}$th of the wavelength. The ratio of intensity at this point to that at the centre of a bright fringe is close to**

(*a*) 0.80
(*b*) 0.74
(*c*) 0.94
(*d*) 0.85

11. **The work function for a metal surface is 4.14 eV. The threshold wavelength for this metal surface is**

(*a*) 4125 Å
(*b*) 2062.5 Å
(*c*) 3000 Å
(*d*) 6000 Å

12. **The radius of the innermost electron orbit of a hydrogen atom is 5.3×10^{-11} m. The radius of the $n = 3$ orbit is**

(*a*) 1.01×10^{-10} m
(*b*) 1.59×10^{-10} m
(*c*) 2.12×10^{-10} m
(*d*) 4.77×10^{-10} m

13. **Which of the following statements about nuclear forces is not true?**

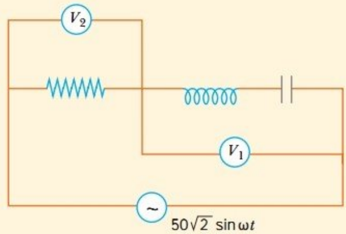
(*a*) The nuclear force between two nucleons falls rapidly to zero as their distance is more than a few femtometres.

(*b*) The nuclear force is much weaker than the Coulomb force.

(*c*) The force is attractive for distances larger than 0.8 fm and repulsive if they are separated by distances less than 0.8 fm.

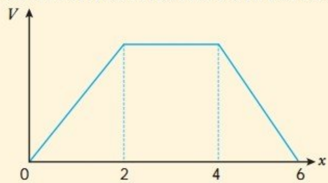
(*d*) The nuclear force between neutron-neutron, proton-neutron and proton-proton is approximately the same.

14. **If the reading of the voltmeter V_1 is 40 V, then the reading of voltmeter V_2 is**



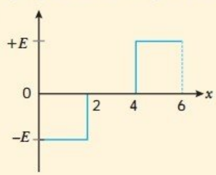
(*a*) 30 V (*b*) 58 V (*c*) 29 V (*d*) 15 V

15. **The electric potential V as a function of distance x is shown in the figure.**

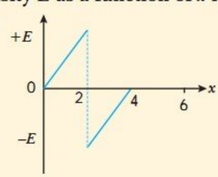


The graph of the magnitude of electric field intensity E as a function of x is

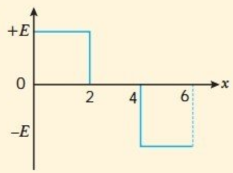
(*a*)



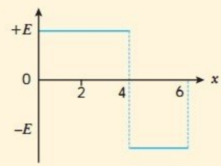
(*b*)



(*c*)



(*d*)



Two statements are given-one labelled Assertion (*A*) and the other labelled Reason (*R*). Select the correct answer to these questions from the codes (*a*), (*b*), (*c*) and (*d*) as given below.

(*a*) **Both *A* and *R* are true and *R* is the correct explanation of *A*.**

(*b*) **Both *A* and *R* are true and *R* is NOT the correct explanation of *A*.**

(*c*) ***A* is true but *R* is false.**

(*d*) ***A* is false and *R* is also false.**

16. **Assertion** (*A*) : The electrical conductivity of a semiconductor increases on doping.
Reason (*R*) : Doping always increases the number of electrons in the semiconductor.

17. **Assertion** (*A*) : In an interference pattern observed in Young's double slit experiment, if the separation (d) between coherent sources as well as the distance (D) of the screen from the coherent sources both are reduced to 1/3rd, then new fringe width remains the same.
Reason (*R*) : Fringe width is proportional to $\left(\frac{d}{D}\right)$.

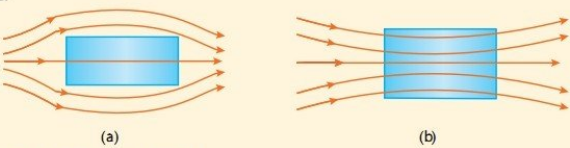
18. **Assertion** (*A*) : The photoelectrons produced by a monochromatic light beam incident on a metal surface have a spread in their kinetic energies.
Reason (*R*) : The energy of electrons emitted from inside the metal surface, is lost in collision with the other atoms in the metal.

SECTION–B

All questions are compulsory. In case of internal choices, attempt any one of them.

19. Electromagnetic waves with wavelength
(*i*) λ_1 is suitable for radar systems used in aircraft navigation.
(*ii*) λ_2 is used to kill germs in water purifiers.
(*iii*) λ_3 is used to improve visibility in runways during fog and mist conditions.
Identify and name the part of the electromagnetic spectrum to which these radiations belong. Also arrange these wavelengths in ascending order of their magnitude.

20. A uniform magnetic field gets modified as shown in figure when two specimens A and B are placed in it.



(*i*) Identify the specimen A and B.
(*ii*) How is the magnetic susceptibility of specimen A different from that of specimen B?

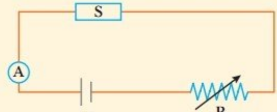
21. What is the nuclear radius of ^{125}Fe, if that of ^{27}Al is 3.6 fermi?

OR

The short wavelength limit for the Lyman series of the hydrogen spectrum is 913.4 Å. Calculate the short wavelength limit for Balmer series of the hydrogen spectrum.

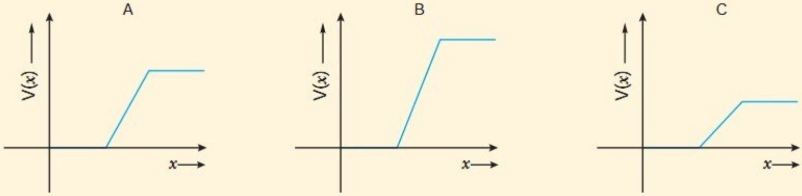
22. A biconvex lens made of a transparent material of refractive index 1.25 is immersed in water of refractive index 1.33. Will the lens behave as a converging or a diverging lens? Justify your answer.

23. The figure shows a piece of pure semiconductor S in series with a variable resistor R and a source of constant voltage V. Should the value of R be increased or decreased to keep the reading of the ammeter constant, when semiconductor S is heated? Justify your answer.



OR

The graph of potential barrier versus width of depletion region for an unbiased diode is shown in graph A. In comparison to A, graphs B and C are obtained after biasing the diode in different ways. Identify the type of biasing in B and C and justify your answer.



24. A narrow slit is illuminated by a parallel beam of monochromatic light of wavelength λ equal to 6000 Å and the angular width of the central maximum in the resulting diffraction pattern is measured. When the slit is next illuminated by light of wavelength λ', the angular width decreases by 30%. Calculate the value of the wavelength λ'.

25. Two large, thin metal plates are parallel and close to each other. On their inner faces, the plates have surface charge densities of opposite signs and of magnitude 17.7×10^{-22} C/m^2. What is electric field intensity E:

(*i*) in the outer region of the first plate, and

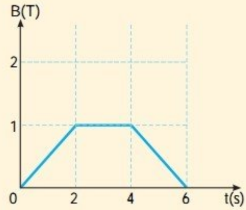
(*ii*) between the plates?

SECTION–C

All questions are compulsory. In case of internal choices, attempt any one of them.

26. Two long straight parallel conductors carrying currents I_1 and I_2 are separated by a distance d. If the currents are flowing in the same direction, show how the magnetic field produced by one exerts an attractive force on the other. Obtain the expression for this force and hence define 1 ampere.

27. The magnetic field through a circular loop of wire 12 cm in radius and 8.5 Ω resistance, changes with time as shown in the figure. The magnetic field is perpendicular to the plane of the loop. Calculate the current induced in the loop and plot a graph showing induced current as a function of time.



28. An *a.c.* source generating a voltage $\varepsilon = \varepsilon_0 \sin \omega t$ is connected to a capacitor of capacitance C. Find the expression for the current I flowing through it. Plot a graph of ε and I versus ωt to show that the current is ahead of the voltage by $\frac{\pi}{2}$.

OR

An *ac* voltage $V = V_0 \sin \omega t$ is applied across a pure inductor of inductance L. Find an expression for the current i, flowing in the circuit and show mathematically that the current flowing through it lags behind the applied voltage by a phase angle of $\frac{\pi}{2}$. Also draw graphs of V and i versus ωt for the circuit.

29. Radiation of frequency 10^{15} Hz is incident on three photosensitive surfaces A, B and C. Following observations are recorded:

Surface A: no photoemission occurs.

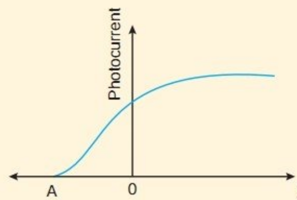
Surface B: photoemission occurs but the photoelectrons have zero kinetic energy.

Surface C: photo emission occurs and photoelectrons have some kinetic energy.

Using Einstein's photo-electric equation, explain the three observations.

OR

The graph shows the variation of photocurrent for a photosensitive metal



(*i*) What does X and A on the horizontal axis represent?

(*ii*) Draw this graph for three different values of frequencies of incident radiation ν_1, ν_2 and ν_3 ($\nu_3 > \nu_2 > \nu_1$) for the same intensity.

(*iii*) Draw this graph for three different values of intensities of incident radiation I_1, I_2 and I_3 ($I_3 > I_2 > I_1$) having the same frequency.

30. The ground state energy of hydrogen atom is –13.6 eV. The photon emitted during the transition of electron from $n = 3$ to $n = 1$ state, is incident on a photosensitive material of unknown work function. The photoelectrons are emitted from the material with the maximum kinetic energy of 9 eV. Calculate the threshold wavelength of the material used.

SECTION–D

All questions are compulsory. In case of internal choices, attempt any one of them.

31. (*i*) Draw equipotential surfaces for (*i*) an electric dipole and (*ii*) two identical positive charges placed near each other.

(*ii*) In a parallel plate capacitor with air between the plates, each plate has an area of 6×10^{-3} m^2 and the separation between the plates is 3 mm.

(*a*) Calculate the capacitance of the capacitor.

(*b*) If the capacitor is connected to 100 V supply, what would be the charge on each plate?

(*c*) How would charge on the plate be affected if a 3 mm thick mica sheet of $k = 6$ is inserted between the plates while the voltage supply remains connected ?.

OR

(*i*) Three charges $-q$, Q and $-q$ are placed at equal distances on a straight line. If the potential energy of the system of these charges is zero, then what is the ratio $Q : q$?

(*ii*) (*a*) Obtain the expression for the electric field intensity due to a uniformly charged spherical shell of radius R at a point distant r from the centre of the shell outside it.

(*b*) Draw a graph showing the variation of electric field intensity E with r, for $r > R$ and $r < R$.

32. (*i*) Explain the term drift velocity of electrons in a conductor. Hence obtain the expression for the current through a conductor in terms of drift velocity.

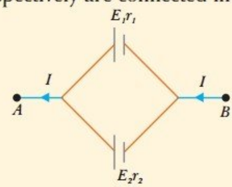
(*ii*) Two cells of emfs E_1 and E_2 and internal resistances r_1 and r_2 respectively are connected in parallel as shown in the figure.

Deduce the expression for the

(*a*) equivalent emf of the combination

(*b*) equivalent internal resistance of the combination

(*c*) potential difference between the points A and B.



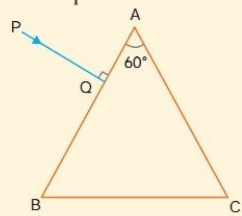
OR

(*i*) State the two Kirchhoff's rules used in the analysis of electric circuits and explain them.

(*ii*) Derive the equation of the balanced state in a Wheatstone bridge using Kirchhoff's laws.

33. (*i*) Draw the graph showing intensity distribution of fringes with phase angle due to diffraction through a single slit. What is the width of the central maximum in comparison to that of a secondary maximum?

(*ii*) A ray PQ is incident normally on the face AB of a triangular prism of refracting angle 60° as shown in figure. The prism is made of a transparent material of refractive index $\frac{2}{\sqrt{3}}$. Trace the path of the ray as it passes through the prism. Calculate the angle of emergence and the angle of deviation.

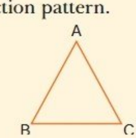


OR

(*i*) Write two points of difference between an interference pattern and a diffraction pattern.

(*ii*) (*a*) A ray of light incident on face AB of an equilateral glass prism, shows minimum deviation of 30°. Calculate the speed of light through the prism.

(*b*) Find the angle of incidence at face AB so that the emergent ray grazes along the face AC.



SECTION–E

CASE STUDY :

34. ***Read the following paragraph and answer the questions.***

A number of optical devices and instruments have been designed and developed such as periscope, binoculars, microscopes and telescopes utilising the reflecting and refracting properties of mirrors, lenses and prisms. Most of them are in common use. Our knowledge about the formation of images by the mirrors and lenses is the basic requirement for understanding the working of these devices.

(*i*) Why the image formed at infinity is often considered most suitable for viewing. Explain

(*ii*) In modern microscopes multicomponent lenses are used for both the objective and the eyepiece. Why?

(*iii*) Write two points of difference between a compound microscope and an astronomical telescope.

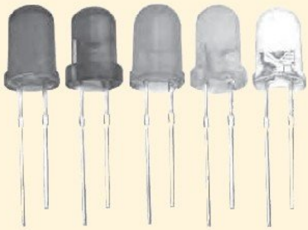
OR

(*iii*) Write two distinct advantages of a reflecting type telescope over a refracting type telescope.

35. ***Read the following paragraph and answer the questions.***

Light emitting diode

LED is a heavily doped P-N junction which under forward bias emits spontaneous radiation. When it is forward biased, due to recombination of holes and electrons at the junction, energy is released in the form of photons. In the case of Si and Ge diode, the energy released in recombination lies in the infrared region. LEDs that can emit red, yellow, orange, green and blue light are commercially available. The semiconductor used for fabrication of visible LEDs must at least have a band gap of 1.8 eV. The compound semiconductor Gallium Arsenide—Phosphide is used for making LEDs of different colours.

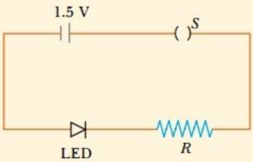


LEDs of different kinds

(*i*) Why are LEDs made of compound semiconductor and not of elemental semiconductors?

(*ii*) What should be the order of bandgap of an LED, if it is required to emit light in the visible range?

(*iii*) A student connects the blue coloured LED as shown in the figure. The LED did not glow when switch S is closed. Explain why ?



OR

(*iii*) Draw V-I characteristic of a $p-n$ junction diode in

(*a*) forward bias and (*b*) reverse bias

ANSWERS

1. (*b*) **2.** (*d*) **3.** (*b*) **4.** (*d*) **5.** (*c*) **6.** (*a*) **7.** (*b*) **8.** (*d*) **9.** (*b*) **10.** (*d*)

11. (*c*) **12.** (*d*) **13.** (*b*) **14.** (*a*) **15.** (*a*) **16.** (*c*) **17.** (*c*) **18.** (*a*)

21. 6 fm **OR** 3653.6 Å

24. 4200 Å

25. (*i*) 0 (*ii*) 2×10^{-10} N/C

27. –2.6 mA, 0, +2.6 mA

30. 4×10^{-7} m

31. (*ii*) (*a*) 17.7×10^{-12} F (*b*) 17.7×10^{-10}C (*c*) 1.062×10^{-8} C **OR** (*i*) 1 : 4

33. (*ii*) 90°, 30° **OR** (*ii*) (*a*) 2.12×10^{8} m/s (*b*) 21.5°

CBSE Examination Paper–2023 (Code: 55/5/1) (Solved)

Time allowed: 3 hours **Maximum marks: 70**

General Instructions:

(i) *This question paper contains **35** questions. **All** questions are **compulsory**.*

(ii) *This question paper is divided into **five** Sections -**A, B, C, D** and **E**.*

(iii) *In **Section A** Questions no. **1** to **18** are Multiple Choice (MCQ) type questions, carrying 1 mark each.*

(iv) *In **Section B** Questions no. **19** to **25** are Short Answer–I (SA-I) type questions, carrying 2 marks each.*

(v) *In **Section C** Questions no. **26** to **30** are Short Answer–II (SA-II) type questions, carrying 3 marks each.*

(vi) *In **Section D** Questions no. **31** to **33** are Long Answer (LA) type questions, carrying 5 marks each.*

(vii) *In **Section E** Questions no. **34** and **35** are case-based questions carrying 4 marks each.*

(viii) *There is no overall choice. However, an internal choice has been provided in 2 questions in Section B, 2 questions in Section C, 3 questions in Section D and 2 questions in Section E.*

(ix) *Use of calculators is **not** allowed.*

Use the following values of physical constants, if required:

$c = 3 \times 10^8$ m/s

$h = 6.63 \times 10^{-34}$ Js

$e = 1.6 \times 10^{-19}$ C

$\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1}

$\varepsilon_0 = 8.854 \times 10^{-12}$ C^2 N^{-1}m^{-2}

$$\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \text{ Nm}^2\text{C}^{-2}$$

Mass of electron $= 9.1 \times 10^{-31}$ kg

Mass of neutron $= 1.675 \times 10^{-27}$ kg

Mass of proton $= 1.673 \times 10^{-27}$ kg

Avogadro's number $= 6.023 \times 10^{23}$ per gram mole

Boltzmann constant $= 1.38 \times 10^{-23}$ JK^{-1}

SECTION–A

1. An electric dipole of length 2 cm is placed at an angle of 30° with an electric field 2×10^5N/C. If the dipole experiences a torque of 8×10^{-3} Nm, the magnitude of either charge of the dipole, is 1

(*a*) 4 μC (*b*) 7 μC

(*c*) 8 mC (*d*) 2 mC

2. Two long parallel wires kept 2 m apart carry 3A current each, in the same direction. The force per unit length on one wire due to the other is 1

(*a*) 4.5×10^{-5} N/m, attractive (*b*) 4.5×10^{-7} N/m, repulsive

(*c*) 9×10^{-7} N/m, repulsive (*d*) 9×10^{-5} N/m, attractive

3. Which of the following has its permeability less than that of free space? 1

(*a*) Copper (*b*) Aluminum

(*c*) Copper chloride (*d*) Nickel

4. **A square shaped coil of side 10 cm, having 100 turns is placed perpendicular to a magnetic field which is increasing at 1 T/s. The induced emf in the coil is** 1

(*a*) 0.1 V (*b*) 0.5 V (*c*) 0.75 V (*d*) 1.0 V

5. **Which one of the following electromagnetic radiation has the least wavelength?** 1

(*a*) Gamma rays (*b*) Microwaves
(*c*) Visible light (*d*) X-rays

6. **In a Young's double-slit experiment, the screen is moved away from the plane of the slits. What will be its effect on the following?** 1

(*i*) Angular separation of the fringes.
(*ii*) Fringe-width

(*a*) Both (*i*) and (*ii*) remain constant (*b*) (*i*) remains constant, but (*ii*) decreases.
(*c*) (*i*) remains constant, but (*ii*) increases. (*d*) Both (*i*) and (*ii*) increase

7. **The energy of a photon of wavelength λ is** 1

(*a*) $hc\lambda$ (*b*) hc/λ
(*c*) λ/hc (*d*) $\lambda h/c$

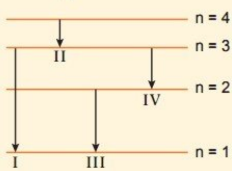
8. **The ratio of the nuclear density of two nuclei having mass numbers 64 and 125 is** 1

(*a*) $\frac{64}{125}$ (*b*) $\frac{4}{5}$
(*c*) $\frac{5}{4}$ (*d*) 1

9. **During the formation of a *p–n* junction.** 1

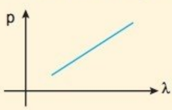
(*a*) diffusion current keeps increasing.
(*b*) drift current remains constant.
(*c*) both the diffusion current and drift current remain constant
(*d*) diffusion current remains almost constant but drift current increases till both currents become equal.

10. **The diagram shows four energy level of an electron in Bohr model of hydrogen atom. Identify the transition in which the emitted photon will have the highest energy.** 1

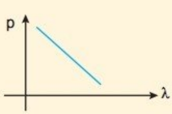


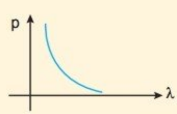
(*a*) I (*b*) II (*c*) III (*d*) IV

11. **Which of the following graphs correctly represents the variation of a particle momentum with its associated de-Broglie wavelength?** 1

(*a*)


(*b*)


(*c*)


(*d*)


12. The capacitors each of 4 μF are to be connected in such a way that the effective capacitance of the combination is 6μF. This can be achieved by connecting 1

(*a*) All three in parallel
(*b*) All three in series
(*c*) Two of them connected in series and the combination in parallel to the third.
(*d*) Two of them connected in parallel and the combination in series to the third.

13. Which of the following statements about a series *LCR* circuit connected to an ac source is correct? 1

(*a*) If the frequency of the source is increased, the impedance of the circuit first decreases and then increases.
(*b*) If the net reactance $(X_L - X_C)$ of circuit becomes equal to its resistance, then the current leads the voltage by 45°.
(*c*) At resonance, the voltage drop across the inductor is more than that across the capacitor.
(*d*) At resonance, the voltage drop across the capacitor is more than that across the inductor.

14. According to Huygens principle the amplitude of secondary wavelets is 1

(*a*) equal in both the forward and the backward directions.
(*b*) maximum in the forward direction and zero in the backward direction.
(*c*) large in the forward direction and small in the backward direction.
(*d*) small in the forward direction and large in the backward direction.

15. The radius of the n^{th} orbit in Bohr model of hydrogen atom is proportional to 1

(*a*) n^2 (*b*) $\frac{1}{n^2}$
(*c*) n (*b*) $\frac{1}{n}$

Questions number 16 to 18 are Assertion (A) and Reason (R) type questions. Two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer from the codes (a), (b), (c) and (d) as given below.

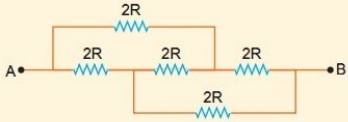
(a) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of the Assertion (A).
(b) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of the Assertion (A).
(c) Assertion (A) is true, but Reason (R) is false.
(d) Assertion (A) is false and Reason (R) is also false.

16. Assertion(*A*) : The resistance of an intrinsic semiconductor decreases with increases in its temperature.

Reason (*R*) : The number of conduction electrons as well as hole increase in an intrinsic semiconductor with rise in its temperature. 1

17. Assertion(*A*) : The equivalent resistance between points *A* and *B* in the given network is $2R$.

Reason (*R*) : All the resistors are connected in parallel. 1



18. Assertion(*A*) : The deflecting torque acting on a current carrying loop is zero when its plane is perpendicular to the direction of magnetic field.

Reason (*R*) : The deflecting torque acting on a loop of magnetic moment $\vec{m}$ in a magnetic field $\vec{B}$ is given by the dot product of $\vec{m}$ and $\vec{B}$. 1

SECTION–B

19. Draw a graph showing the variation of potential energy of a pair of nucleons as a function of their separation. Indicate the region in which the nuclear force is (*a*) attractive and (*b*) repulsive. **2**

20. (*a*) How will the de Broglie wavelength associated with an electron be affected when the (*i*) velocity of the electron decreases? and (*ii*) accelerating potential is increased? Justify your answer. **2**

OR

(*b*) How would the stopping potential for a given photosensitive surface change if (*i*) the frequency of the incident radiation were increased? and (*ii*) the intensity of incident radiation were decreased? Justify your answer.

21. Identify the electromagnetic wave whose wavelengths range is from about

(*a*) 10^{-12} m to about 10^{-8} m. (*b*) 10^{-3} m to about 10^{-1} m.

Write one use of each **2**

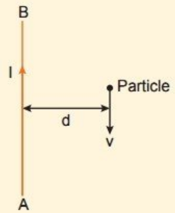
22. Depict the orientation of an electric dipole in (*a*) stable and (*b*) unstable equilibrium in an external uniform electric field.

Write the potential energy of the dipole in each case. **2**

23. (*a*) Write the expression for the Lorentz force on a particle of charge q moving with a velocity $\vec{v}$ in a magnetic field $\vec{B}$. When is the magnitude of this force maximum? Show that no work is done by this force on the particle during its motion from a point $\vec{r_1}$ to point $\vec{r_2}$. **2**

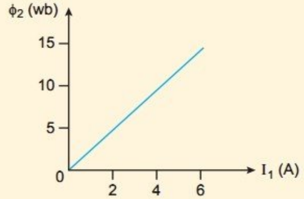
OR

(*b*) A long straight wire AB carries a current I. A particle (mass m and charge q) moves with a velocity $\vec{v}$, parallel to the wire, at a distance d from it as shown in the figure. Obtain the expression for the force experienced by the particle and mention its direction.



24. The potential difference applied across a given conductor is doubled. How will this affect (*i*) the mobility of electrons and (*ii*) the current density in the conductor? Justify your answers. **2**

25. Two coils C_1 and C_2 are placed close to each other. The magnetic flux ϕ_2 linked with the coil C_2 varies with the current I_1 flowing in coil C_1 as shown in the figure. Find **2**



(*a*) the mutual inductance of the arrangement and

(*b*) the rate of change of current $\left(\dfrac{dI_1}{dt}\right)$ that will induce an emf of 100 V in coil C_2.

SECTION–C

26. (*a*) A plane wave-front propagating in a medium of refractive index 'μ_1' is incident on a plane surface making an angle of incidence (*i*). It enters into a medium of refractive index μ_2 $(\mu_2 > \mu_1)$.

Use Huygen's construction of secondary wavelets to trace the refracted wave-front. Hence verify Snell's law of refraction. **3**

OR

(*b*) Using Huygen's construction, show how a plane wave is reflected from a surface. Hence verify the law of reflection.

27. An alternating voltage of 220 V is applied across a device *X*. A current of 0.22 A flows in the circuit and it lags behind the applied voltage in phase by $\pi/2$ radian. When the same voltage is applied across another device *Y*. The current in the circuit remains the same and it is in phase with the applied voltage.

(*a*) Name the devices *X* and *Y* and,

(*b*) Calculate the current flowing in the circuit when the same voltage is applied across the series combination of *X* and *Y*. **3**

28. State the basic principle behind the working of an ac generator. Briefly describe its working and obtain the expression for the instantaneous value of emf induced. **3**

29. (*a*) Briefly describe how the current sensitivity of a moving coil galvanometer can be increased.

(*b*) A galvanometer shows full scale deflection for current I_g. A resistance R_1 is required to convert it into a voltmeter of range (0 – V) and a resistance R_2 to convert it into a voltmeter of range (0 – 2V). Find the resistance of the galvanometer. **3**

30. (*a*) (*i*) Differentiate between 'distance of closest approach' and 'impact parameter'.

(*ii*) Determine the distance of closest approach when an alpha particle of kinetic energy 3.95 MeV approaches a nucleus of Z = 79, stops and reverses its directions. **3**

OR

(*b*) (*i*) State three postulates of Bohr's theory of hydrogen atom.

(*ii*) Find the angular momentum of an electron revolving in the second orbit in Bohr's hydrogen atom.

SECTION–D

31. (*a*) (*i*) Explain how free electrons in a metal at constant temperature attain an average velocity under the action of an electric field. Hence obtain an expression for it.

(*ii*) Consider two conducting wires *A* and *B* of the same diameter but made of different materials joined in series across a battery. The number density of electrons in *A* is 1.5 times that in *B*. Find the ratio of drift velocity of electrons in wire *A* to that in wire *B*. **5**

OR

(*b*) (*i*) A cell emf of (*E*) and internal resistance (*r*) is connected across a variable load resistance (*R*). Draw plots showing the variation of terminal voltage *V* with (*i*) *R* and (*ii*) the current (*I*) in the load.

(*ii*) Three cells, each of emf *E* but internal resistances 2*r*, 3*r* and 6*r* are connected in parallel across a resistor *R*.

Obtain expressions for (*i*) current flowing in the circuit and (*ii*) the terminal potential difference across the equivalent cell.

32. (*a*) Draw the circuit arrangement for studying *V–I* characteristics of a *p-n* junction diode in (*i*) forward biasing and (*ii*) reverse biasing. Draw the typical *V–I* characteristics of a silicon diode. Describe briefly the following terms: (*i*) minority carrier injection in forward biasing and (*ii*) breakdown voltage in reverse biasing. **5**

OR

(*b*) Name two important processes involved in the formation of a *p-n* junction diode. With the help of a circuit diagram, explain the working of junction diode as a full wave rectifier. Draw its input and output waveforms. State the characteristic property of a junction diode that makes it suitable for rectification.

33. (*a*) (*i*) Draw a ray diagram to show the working of a compound microscope. Obtain the expression for the total magnification for the final image to be formed at the near point.

(*ii*) In a compound microscope an object is placed at a distance of 1.5 cm from the objective of focal length 1.25 cm. If the eye-piece has a focal length of 5 cm and the final image is formed at the near point, find the magnifying power of the microscope. **5**

OR

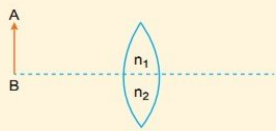
(*b*) (*i*) Draw a ray diagram for the formation of image of an object by an astronomical telescope, in normal adjustment. Obtain the expression for its magnifying power.

(*ii*) The magnifying power of an astronomical telescope in normal adjustment is 2.9 and the objective and the eyepiece are separated by a distance of 150 cm. Find the focal lengths of the two lenses.

SECTION–E

34. A lens is a transparent optical medium bounded by two surface: at least one of which should be spherical. Considering image formation by a single spherical surface successively at the two surfaces of a lens. Lens maker's formula is obtained. It is useful to design lenses of desired focal length using surfaces of suitable radii of curvature. This formula helps us obtain a relation between u, v and f for a lens. Lenses form images of objects and they are used in a number of optical devices. for example microscope and telescopes.

(*i*) An object AB is kept in front of a composite convex lens. As shown in figure. Will the lens produce one image? If not, explain.



(*ii*) A real image of an object formed by a convex lens is observed on a screen. If the screen is removed will the image still be formed? Explain.

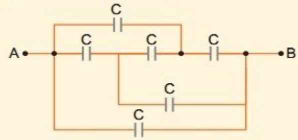
(*iii*) A double convex lens is made of glass of refractive index 1.55 with both faces of the same radius of curvature. Find the radius of curvature required if focal length is 20 cm. **4**

OR

(*iii*) Two convex lenses A and B focal lengths 15 cm and 10 cm respectively are placed coaxially 'd' distance apart. A point object is kept at a distance of 30 cm in front of lens A. Find the value of 'd' so that the rays emerging from lens B are parallel to its principal axis.

35. A capacitor is a system of two conductors separated by an insulator. The two conductors have equal and opposite charges with a potential difference between them. The capacitance of a capacitor depends on the geometrical configuration (Shape, size and separation) of the system and also on the nature of the insulator separating the two conductors. They are used to store charges. Like resistors, capacitors can be arranged in series or parallel or a combination of both to obtain desired value of capacitance. **4**

(*i*) Find the equivalent capacitance between points A and B in the given diagram.

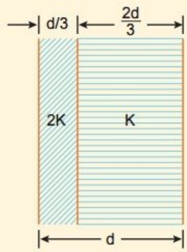


(*ii*) A dielectric slab is inserted between the plates of a parallel plate capacitor. The electric field between the plates decreases. Explain.

(*iii*) A capacitor A of capacitance C, having charge Q is connected across another uncharged capacitor B of capacitance $2C$. Find an expression for (*a*) the potential difference across the combination and (*b*) the charge lost by capacitor A.

OR

(*iii*) Two slabs of dielectric constants $2K$ and K fill the space between the plates of a parallel plate capacitor of plate area A and plate separation D as shown in figure. Find and expression for capacitance of the system.



ANSWERS

SECTION–A

1. (*a*) As we know $\tau = pE\sin\theta$ $\quad [p = qd]$

$$\Rightarrow p = \frac{\tau}{E\sin\theta}$$

$$\Rightarrow qd = \frac{\tau}{E\sin\theta} \Rightarrow q = \frac{\tau}{Ed\sin 30^\circ} \qquad [\sin 30^\circ = \frac{1}{2}]$$

$$= \frac{8\times10^{-3}}{2\times10^{5}\times2\times10^{-2}\times\frac{1}{2}} = 4\mu\text{C}$$

2. (*)Force per unit length, $f = \dfrac{\mu_0 I_1 I_2}{2\pi d} = \dfrac{4\pi\times10^{-7}\times3\times3}{2\pi\times2}$ $\quad [I_1 = I_2 = 3\text{A}]$

$$= 9\times10^{-7}\ \text{N/m}.$$

Both parallel wire carry same current in same direction so, the magnetic forces are attractive in nature. [*NOTE : No any option is correct in this questions.]

3. (*a*) A diamagnetic material creates a magnetic field opposing that of the external magnetic field and it repels the external magnetic field. Hence its permeability is less than that of free space.

4. (*d*) Emf induced, $e = \left|-N\frac{d\phi}{dt}\right| = NA\frac{dB}{dt}$

$$= 100 \times (10 \times 10^{-2}) \times 1 = 1\text{V}$$

5. (*a*) Gamma rays has shortest wavelength because it has highest frequency.

6. (*c*) As we know, Angular fringe width, $\theta = \frac{\lambda}{d}$ and Fringe width, $\beta = \frac{\lambda D}{d}$

Hence, if D increases, then θ remains constant but β increases.

7. (*b*) Energy of photon, $E = h\upsilon = \frac{hc}{\lambda}$ $[\upsilon = \frac{c}{\lambda}]$

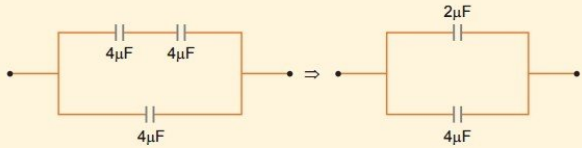
8. (*d*) Nuclear density is independent of mass number (A).

9. (*d*) In formation of a p-n junction, both drift and diffusion occurs. In an unbiased p-n junction, drift current is equal and opposite to the diffusion current and hence net current is zero.

10. (*a*) In emission line I, energy is emitted. Also in the emission lines II, III and IV, energy is emitted. The line having maximum energy is I, because energy difference between successive levels decreases rapidly with increase of n.

11. (*d*) As from relation, $\lambda = \frac{h}{p} \Rightarrow \lambda \propto \frac{1}{p}$

12. (*c*) Here, $C_1 = C_2 = C_3 = 4\mu\text{F}$.



Hence, $C_{eq} = 2 + 4 = 6\mu\text{F}$.

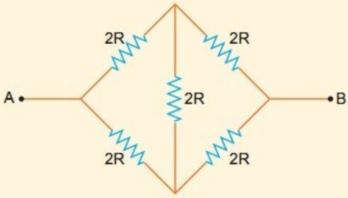
13. (*a*) If the frequency of the source is increased the impedance of the circuit first decreases and then increases.

14. (*b*) Hygen's principle states that each point on a given wave front is a source of secondary wavelets or secondary disturbance. Further, the disturbances originating from the secondary sources spreads in all directions in the same way as originating from the primary source and the amplitude of secondary wavelets is maximum in the forward direction and zero in the backward direction.

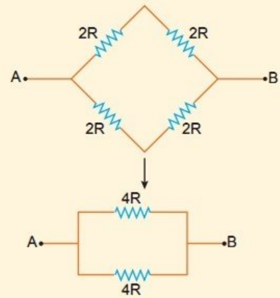
15. (*a*) As we know, $r_n = \frac{\varepsilon_o h^2 n^2}{\pi m Z e^2} \Rightarrow r_n \propto n^2$

16. (*a*) Both Assertion (A) and Reason (R) are true and (R) is the correct explanation of (A).

17. (*c*) From the given circuit shown,



the above circuit is fulfill the balanced condition of W.S.B so, current through $2R$ (middle part) is zero.



Now,

$R_1 = 2R + 2R = 4R$

$R_2 = 2R + 2R = 4R$

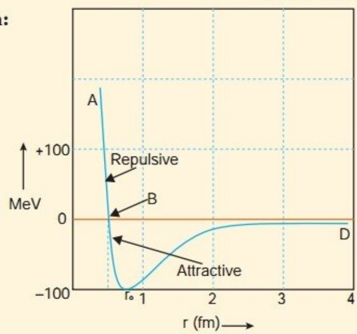
So, $R_{AB} = \dfrac{4R \times 4R}{4R + 4R} = \dfrac{16R^2}{8R} = 2R$

18. (*c*) Here, the angle between area vector of current carrying loop and magnetic field is zero. So,

$$|\vec{\tau}| = |\vec{m} \times \vec{B}| = mB \sin\theta \qquad [\theta = 0°]$$
$$= 0$$

SECTION–B

19. Graph:



Repulsive nuclear force for $r < r_0$

Attractive nuclear force for $r > r_0$

20. (*a*) (*i*) According to de-Broglie hypothesis, $\lambda = \dfrac{h}{p} = \dfrac{h}{mv}$ $\qquad [p = mv]$

If v decreases, then λ increases.

(*ii*) As from relation, $\lambda = \dfrac{12.27}{\sqrt{V}} \Rightarrow \lambda \propto \dfrac{1}{\sqrt{V}}$

If V increase then λ decreases

OR

(*b*) (*i*) By Einstein's photo electric equation,

$$eV_0 = h\nu - h\nu_0$$

$$V_0 = \frac{h}{e}(\nu - \nu_0)$$

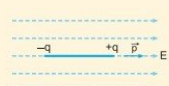
Hence, If ν increases, then V_0 increases.

(*ii*) remains constant because it is independent from intensity of incident radiation.

21. (*a*) **X-rays:** Used as a diagnostic tool in medicine and as a treatment for certain forms of cancer.

(*b*) **Microwaves:** Used in radar systems for aircraft navigation.

22. (*a*) Stable equilibrium, $\theta = 0°$ *i. e*, $\vec{p}$ is parallel to $\vec{E}$

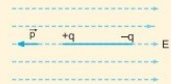


$U = -PE \cos\theta$

$= -PE \cos 0°$

$= -PE$

(*b*) Unstable equilibrium, $\theta = 180°$ *i.e*, $\vec{p}$ is anti parallel to $\vec{E}$



$$U = -PE\cos\theta$$
$$= -PE\cos 180°$$
$$= +PE$$

23. (*a*) Lorentz magnetic force, $\vec{F}_m = q\vec{v} \times \vec{B}$

If charge particle (q) moves perpendicular to the magnetic field (*i.e.*, $\vec{v} \perp \vec{B}$,) then

$$|\vec{F}| = q|\vec{v} \times \vec{B}| = qvB\sin 90° = qvB \text{ (maximum)}$$

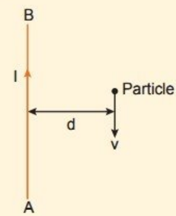
Work done, $W = \vec{F}_m \vec{S} = \int \vec{F}_m \vec{v} dt = \int q(\vec{v} \times \vec{B}).\vec{v}\, dt$

As $(\vec{v} \times \vec{B}).\vec{v} = 0$ $\qquad [\because \vec{v} \times \vec{B} \perp \vec{v}]$

$\therefore$ Work, $W = 0$

OR

(*b*) Magnetic field due to long straight conductor at distance (d) is $B = \dfrac{\mu_0 I}{2\pi d}$



by Lorentz's Force,

$$\vec{F} = q\vec{v} \times \vec{B}$$
$$|\vec{F}| = qvB\sin\theta \qquad [\theta = 90°]$$
$$= qvB$$
$$= qv\left(\frac{\mu_0 I}{2\pi d}\right) = \frac{\mu_0 Iqv}{2\pi d}$$

Force acts along east direction or away from conductor towards right side of the conductor.

24. (*i*) As we know, $\mu = \dfrac{v_d}{E} = \dfrac{e\tau}{m}$

Hence, μ is independent from potential difference applied across conductor. So it remain constant.

(*ii*) As from point form of Ohm's Law, $J = \sigma E$

$$\Rightarrow J \propto E \qquad [E = \frac{V}{L}]$$

Also, $J \propto V$

Hence if V becomes doubled then J also becomes doubled.

25. (*i*) The slope of ϕ-I graph gives mutual inductance of the arrangement. (*i.e.*, $\phi \propto I \Rightarrow \phi = MI$)

$$\text{i.e., } M = \frac{\Delta\phi_2}{\Delta I_1} = \frac{10-0}{4-0} = \frac{10}{4} = 2.5\text{H.}$$

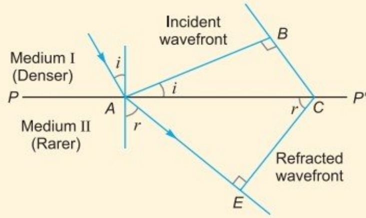
(*ii*) Here, $e = 100$V

$$\text{induced emf, } e = \left|-M\frac{dI_1}{dt}\right| = 2.5 \times \frac{dI_1}{dt}$$

$$\therefore \qquad \frac{dI_1}{dt} = \frac{100}{2.5} = 40 \text{ A/s}$$

SECTION–C

26. (*a*) We assume a plane wavefront AB propagating in denser medium incident on the interface PP' at angle i as shown in Fig. Let t be the time taken by the wave front to travel a distance BC. If v_1 is the speed of the light in medium I.



So, $BC = v_1 t$

In order to find the shape of the refracted wavefront, we draw a sphere of radius $AE = v_2 t$, where v_2 is the speed of light in medium II (rarer medium). The tangent plane CE represents the refracted wavefront.

In ΔABC, $\sin i = \dfrac{BC}{AC} = \dfrac{v_1 t}{AC}$

and in ΔACE, $\sin r = \dfrac{AE}{AC} = \dfrac{v_2 t}{AC}$

$$\therefore \quad \frac{\sin i}{\sin r} = \frac{BC}{AE} = \frac{v_1 t}{v_2 t} = \frac{v_1}{v_2} \qquad \ldots(i)$$

Let c be the speed of light in vacuum

So, $\quad n_1 = \dfrac{c}{v_1}$ and $n_2 = \dfrac{c}{v_2}$

$$\frac{n_2}{n_1} = \frac{v_1}{v_2} \qquad \ldots(ii)$$

From equations (*i*) and (*ii*), we have

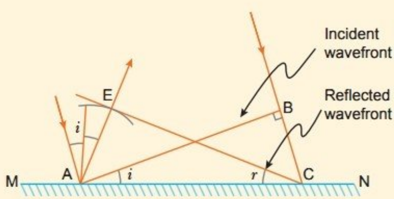
$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1}$$

$$n_1 \sin i = n_2 \sin r$$

It is known as Snell's law.

OR

(*b*)



Consider a plane wave AB incident at an angle i on a reflecting surface MN. If v is the speed of the wave in the medium and if τ represents the time taken by the wavefront to advance from the point B to C then the distance

$$BC = v\,\tau$$

In order to construct the reflected wavefront, draw a sphere of radius $v\tau$ from the point A. Let CE represent the tangent plane, drawn from the point C to this sphere.

In ΔAEC and ΔABC,

$$
\begin{aligned}
AE &= BC = v\tau \\
\angle CEA &= \angle ABC \text{ (90° each)} \\
AC &= AC \qquad \text{(Common Side)} \\
\Delta AEC &\cong \Delta ABC \qquad \text{(by RHS Congruency)} \\
\therefore \quad \angle i &= \angle r
\end{aligned}
$$

This is the law of reflection.

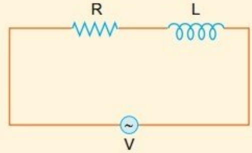
27. (*i*) If I lags behind the applied voltage (V) by $\frac{\pi}{2}$ road, then circuit must be pure inductor type. So, X is inductor.

If I is in phase with applied voltage (V) then circuit must be purely resistive type. So, Y is resistor.

(*ii*) When circuit is purely induetive, $X_L = \frac{V_{rms}}{I_{rms}} = \frac{220}{0.22} = 1000\ \Omega$

Again, when circuit is purely resistive,

$$R = \frac{V_{rms}}{I_{rms}} = \frac{220}{0.22} = 1000\ \Omega$$

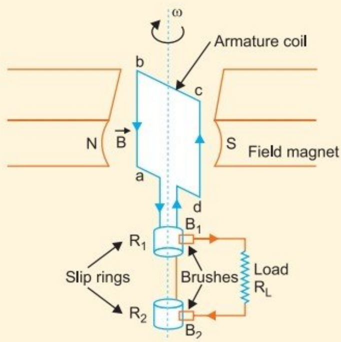


Now, $Z = \sqrt{R^2 + X_L^2}$

$$= 1000\sqrt{2}\ \Omega$$

Hence, $I = \frac{V_{rms}}{I_{rms}} = \frac{220}{1000\sqrt{2}} = 0.16$ A

28. AC generator: A dynamo or generator is a device which converts mechanical energy into electrical energy.



Principle: It works on the principle of electromagnetic induction. When a coil rotates continuously in a magnetic field, the effective area of the coil linked normally with the magnetic field lines, changes continuously with time. This variation of magnetic flux with time results in the production of an alternating emf in the coil.

Working: When the armature coil is rotated in the strong magnetic field, the magnetic flux linked with the coil changes and the current is induced in the coil, its direction being given by Fleming's right hand rule. Considering the armature to be in vertical position and as it rotates in clockwise direction, the wire ab moves downward and cd upward, so that the direction of induced current is shown in fig. In the external circuit, the current flows along B_1 RL B_2. The direction of current remains unchanged during the first half turn of armature. During the second half revolution, the wire ab moves upward and cd downward, so the direction of current is reversed and in external circuit it flows along B_1 RL B_2. Thus the direction of induced emf and current changes in the external circuit after each half revolution.

Expression for Induced emf: When the coil is rotated with a constant angular speed ω, the angle θ between the magnetic field vector B and the area vector A of the coil at any instant t is $\theta = \omega t$ (assuming $\theta = 0°$ at $t = 0$). As a result, the effective area of the coil exposed to the magnetic field lines changes with time, the flux at any time t is

$$\phi = BA\cos\theta = BA\cos\omega t$$

From Faraday's law, the induced emf for the rotating coil of N turns is then,

$$\varepsilon = -N\frac{d\phi_B}{dt} = -NBA\frac{d}{dt}(\cos\omega t)$$

Thus, the instantaneous value of the emf is

$$\varepsilon = NBA\,\omega\sin\omega t$$

where $NBA\omega = 2\pi\upsilon NBA$ is the maximum value of the emf, which occurs when $\sin \omega t = \pm 1$. If we denote $NBA\omega$ as ε_0, then

$$\varepsilon = \varepsilon_0 \sin \omega t \Rightarrow \varepsilon = \varepsilon_0 \sin 2\pi\nu t$$

where ν is the frequency of revolution of the generator's coil.

Obviously, the emf produced is alternating and hence the current is also alternating.

29. (*a*) Current sensitivity of moving coil galvanometer can be increased by

(*i*) increasing number of turns in the coil ($I_s \propto N$)

(*ii*) increasing magnetic field strength ($I_s \propto B$)

(*ii*) using a material having lesser value of torsional constant $\left(I_s \propto \frac{1}{k}\right)$

(*iv*) increasing area of cross-section of the coil (*Any one*)

(*b*) Let I_g be the current through galvanometer at full deflection and G be the resistance of galvanometer.

For voltmeter range, (0 – V)

$$V = I_g (G + R_1) \quad \text{...}(i)$$

For range, (0 – 2V)

$$2V = I_g (G + R_2) \quad \text{...}(ii)$$

by diving (*ii*) and (*i*)

$$2 = \frac{(G + R_2)}{G + R_1}$$

$$\Rightarrow \quad 2G + 2R_1 = G + R_2$$

$$\therefore \quad G = R_2 - 2R_1$$

30. (*a*) (*i*)

Distance of Closest Approach	Impact Parameter
The smallest distance of approach of α-particle near heavy nucleus is a measure of the size of nucleus. Distance of nearest approach ≈ size of nucleus = $\frac{1}{4\pi\varepsilon_0}\frac{2Ze^2}{E_K}$ where E_K is kinetic energy of incident α-particle, Z = atomic number, e = electronic charge.	The perpendicular distance of initial velocity vector of α-particle from the nucleus, when the particle is far away from the nucleus, is called the impact parameter. It is denoted by b. For head on approach of α-particle, b = 0.

(*ii*) Let r be the center to center distance between the alpha particle and the nucleus (Z = 79). When the alpha particle is at the stopping point, then

$$K = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(2e)}{r}$$

$$\therefore \quad r = \frac{1}{4\pi\varepsilon_0}\frac{2Ze^2}{K}$$

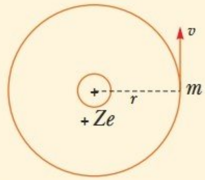
$$= \frac{9 \times 10^9 \times 2 \times 79 \times (1.6 \times 10^{-19})^2}{3.95 \times 10^6 \times 1.6 \times 10^{-19}} = 5.76 \times 10^{-14}\text{m}.$$

OR

(*b*) (*i*) **Bohr's Postulates for H-atom:**

- **Stationary Circular Orbits:** An atom consists of a central positively charged nucleus and negatively charged electrons revolve around the nucleus in certain orbits called **stationary orbits.**

The electrostatic coulomb force between electrons and the nucleus provides the necessary centripetal force.



i.e., $\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(e)}{r^2}$

where Z is the atomic number, m is the mass of electrons, r = radius of orbit.

- **Quantum Condition:** The stationary orbits are those in which angular momentum of electron is an integral multiple of $\frac{h}{2\pi}$, *i.e.*,

  $mvr = n\frac{h}{2\pi}, \quad n = 1, 2, 3,...$

Integer n is called the principal quantum number. This equation is called Bohr's quantum condition.

- **Transitions:** The electron does not radiate energy when in a stationary orbit. The quantum of energy (or photon) is emitted or absorbed when an electron jumps from one stationary orbit to the other. The frequency of emitted or absorbed photon is given by

  $h\nu = |E_i - E_f|$

  This is called Bohr's frequency condition.

(*ii*) Here, $n = 2$

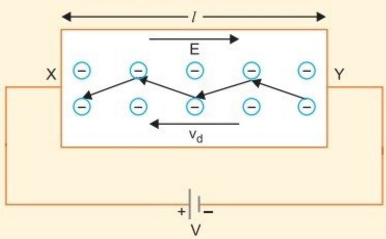
So, angular momentum,

$$L = \frac{nh}{2\pi} = \frac{2h}{2\pi} = \frac{h}{\pi}$$

$$= \frac{6.63\times10^{-34}}{3.14} = 2.1\times10^{-34} \text{ kg m}^2\text{ s}^{-1}$$

SECTION–D

31. (*a*) (*i*) Consider a metallic conductor XY of length l and cross-sectional area A. A potential difference V is applied across the conductor XY. Due to this potential difference an electric field $\vec{E}$ is produced in the conductor. The magnitude of electric field strength $E = \frac{V}{l}$ and its direction is from X to Y.



This electric field exerts a force on free electrons; due to which electrons are accelerated. The electric force on electron $\vec{F} = -e\vec{E}$ (where $e = 1.6 \times 10^{-19}$ coulomb).

If m is the mass of electron, then its acceleration

$$\vec{a} = \frac{\vec{F}}{m} = -\frac{e\vec{E}}{m} \qquad ...(i)$$

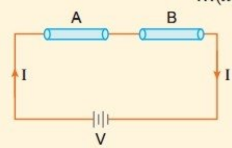
This acceleration remains constant only for a very short duration, since there are random forces which deflect the electron in random manner. These deflections may arise as

- ions of metallic crystal vibrate simple harmonically around their mean positions. Different ions vibrate in different directions and may be displaced by different amounts.
- direct collisions of electrons with atoms of metallic crystal lattice.

In any way after a short duration called relaxation time, the motion of electrons become random. Thus, we can imagine that the electrons are accelerated only for a short duration. As average velocity of random motion is zero, if we consider the average motion of an electron, then its initial velocity is zero, so the velocity of electron after time τ (*i.e.*, drift velocity $\vec{v}_d$) is given by the relation $\vec{v} = \vec{u} + \vec{a}t$

(here $\vec{u} = 0, v = \vec{v}_d, t = \tau, \vec{a} = -\frac{e\vec{E}}{m}$)

$$\vec{v}_d = 0 - \frac{e\vec{E}}{m}\tau \quad \Rightarrow \vec{v}_d = -\frac{e\tau}{m}\vec{E} \qquad ...(ii)$$



At given temperature, the relaxation time τ remains constant, so drift velocity remains constant.

(*ii*) Here, $d_1 = d_2 =$ same, $n_A = 1.5 n_B$

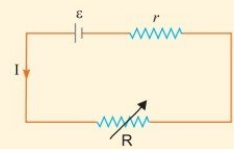
$I =$ Constant (in seriess)

As we have, $I = neAv_d$ Where $[A, e, I = \text{Constant}]$

So, $v_d \propto \frac{1}{n}$

$$\therefore \frac{(v_d)_A}{(v_d)_B} = \frac{n_B}{n_A} = \frac{1}{1.5} = \frac{2}{3}$$

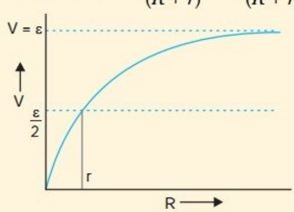
OR



(*b*) (*i*) From the circuit shown,

$\varepsilon = V + Ir$

Also, $V = IR = \frac{\varepsilon}{(R+r)} R = \frac{\varepsilon}{(R+r)/R} = \frac{\varepsilon}{1 + \frac{r}{R}}$

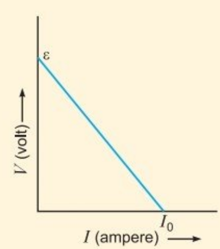


(*ii*) From voltage equation,

$V = \varepsilon - Ir \Rightarrow r = \frac{\varepsilon - V}{I}$

At $I = 0, V = \varepsilon$

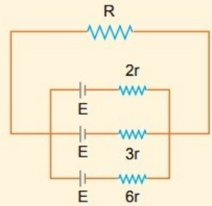
When $V = 0, I = I_0, R = \frac{\varepsilon}{I_0}$



The inter cept on Y–axis gives the emf of the cell.
The stop of graph give the internal resistances.

(*iii*) From circuit shown,

For parallel combination of cells



$$E_{net} = \frac{\frac{E_1}{r_1} + \frac{E_2}{r_2} + \frac{E_3}{r_3}}{\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}}$$

$$= \frac{\frac{E}{2r} + \frac{E}{3r} + \frac{E}{6r}}{\frac{1}{2r} + \frac{1}{3r} + \frac{1}{6r}} = \frac{3E + 2E + E}{3 + 2 + 1} = \frac{6E}{6} = E$$

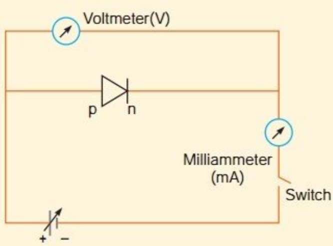
And $\quad \frac{1}{r_{net}} = \frac{1}{2r} + \frac{1}{3r} + \frac{1}{6r} = \frac{3 + 2 + 1}{6r} = \frac{1}{r}$

$\therefore r_{net} = r$

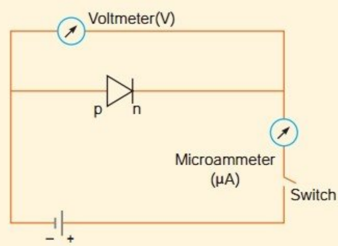
(1) Total current, $I = \frac{E_{net}}{R + r} = \frac{E}{(R + r)}$

(2) Terminal P. d, $V = E - Ir = E - \left(\frac{E}{R + r}\right)r = \frac{E\,R}{(R + r)}$

32. (*a*) Circuit diagram:

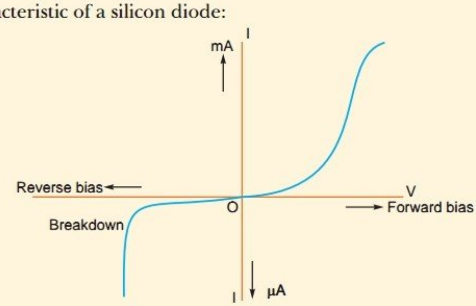


Forward Bias



Reverse Bias

$V - I$ characteristic of a silicon diode:



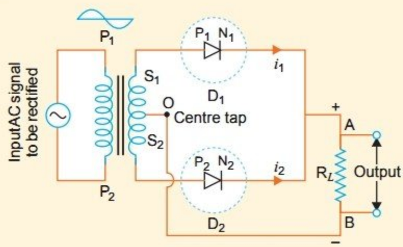
(*i*) **Minority Carrier Injection:** Due to the applied voltage, electrons from n-side cross the depletion region and reach p-side (where they are minority carriers). Similarly, holes from p-side cross this junction and reach the n-side (where they are minority carriers). This process under forward bias is known as minority carrier injection.

(ii) **Breakdown Voltage:** It is a critical reverse bias voltage at which current is independent of applied voltage.

OR

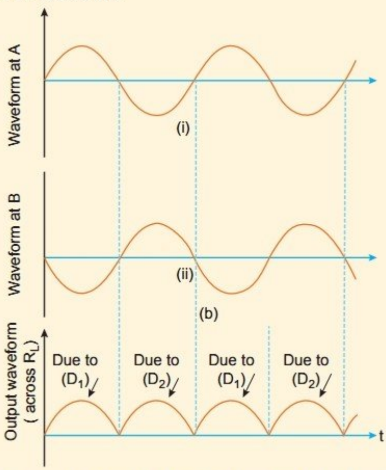
(*b*) Two important process occurring during the formation of p-n junction are diffusion and drift.

Circuit diagram:



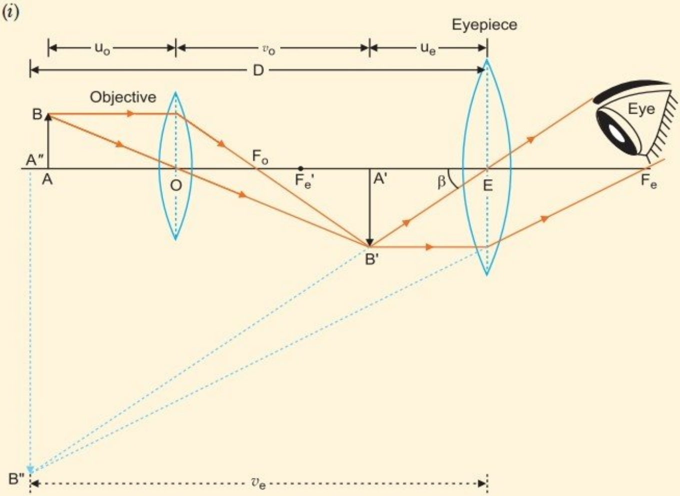
Working: The ac input voltage across secondary S_1 and S_2 changes polarity after each half cycle. Suppose during the first half cycle of input ac signal, the terminal S_1 is positive relative to centre tap O and S_2 is negative relative to O. Then diode D_1 is forward biased and diode D_2 is reverse biased. Therefore, diode D_1 conducts while diode D_2 does not. The direction of current (i_1) due to diode D_1 in load resistance R_L is directed from A to B In next half cycle, the terminal S_1 is negative and S_2 is positive relative to centre tap O. The diode D_1 is reverse biased and diode D_2 is forward biased. Therefore, diode D_2 conducts while D_1 does not. The direction of current (i_2) due to diode D_2 in load resistance R_L is still from A to B. Thus, the current in load resistance R_L is in the same direction for both half cycles of input *ac* voltage. Thus for input ac signal the output current is a continuous series of unidirectional pulses.

Input and output waveforms.



A junction diode allows current to pass only when it is forward biased. So, if an alternating voltage is applied across a diode the current flows only in that part of the cycle when the diode is forward biased. This property is used to rectify alternating voltages and the circuit used for this purpose is called a rectifier.

33. (*a*) (*i*)



Working : Suppose a small object AB is placed slightly away from the first focus F_0' of the objective lens. The objective lens forms the real, inverted and magnified image $A'\,B'$ which acts as an object for eyepiece. The eyepiece is so adjusted that the image $A'\,B'$ lies between the first focus F_e' and the eyepiece E. The eyepiece forms its image $A''\,B''$ which is virtual, erect and magnified. Thus the final image $A''\,B''$ formed by the microscope is inverted and magnified and its position is outside the objective and eyepiece towards objective lens.

Magnifying power of a microscope is defined as the ratio of angle (β) subtended by final image on the eye to the angle (α) subtended by the object on eye, when the object is placed at the least distance of distinct vision, *i.e.*,

Magnifying power, $M = \dfrac{\beta}{\alpha}$.

As object is very small, angles α and β are very small and so tan α = α and tan β = β. By definition the object AB is placed at the least distance of distinct vision.

$$\tan\alpha = \alpha = \frac{AB}{EA}$$

By sign convention $\quad EA = -D, \qquad \therefore \quad \alpha = \dfrac{AB}{-D}$

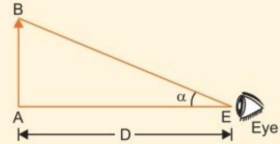
and from figure $\qquad \tan\beta = \beta = \dfrac{A'B'}{EA'}$

If u_e is distance of image $A'\,B'$ from eye-piece E, then by sign convention, $EA' = -\,u_e$

and so, $\qquad \beta = \dfrac{A'B'}{(-u_e)}$

Hence magnifying power $M = \dfrac{\beta}{\alpha} = \dfrac{A'B'/(-u_e)}{AB/(-D)} = \dfrac{A'B'}{AB}\cdot\dfrac{D}{u_e}$

By sign conventions, magnification of objective lens



$$\frac{A'B'}{AB} = \frac{v_0}{(-u_0)}$$

$$M = -\frac{v_0}{u_0}.\frac{D}{u_e}$$

Using lens formula $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ for eye-lens, (*i.e.*, using $f = f_e$, $v = v_e$, $u = -u_e$), we get

$$\frac{1}{f_e} = \frac{1}{-v_e} - \frac{1}{(-u_e)} \quad \text{or} \quad \frac{1}{u_e} = \frac{1}{f_e} + \frac{1}{v_e}$$

Magnifying power, $\quad M = -\frac{v_0}{u_0} D\left(\frac{1}{f_e} + \frac{1}{v_e}\right)$

or $\quad M = -\frac{v_0}{u_0}\left(\frac{D}{f_e} + \frac{D}{v_e}\right)$

When final image is formed at the distance of distinct vision, $v_e = D$

Magnification, $M = -\frac{v_0}{u_0}\left(1 + \frac{D}{f_e}\right)$

For greater magnification of a compound microscope, f_e should be small. As $f_0 < f_e$, so f_0 is small. Hence, for greater magnification both f_0 and f_e should be small with f_0 to be smaller of the two.

(*ii*) Here, $u_0 = 1.5$ cm, $f_0 = 1.25$ cm, $f_e = 5$ cm [image formed at near point]

then, From less formula, $\frac{1}{f_0} = \frac{1}{v_0} - \frac{1}{u_0}$

$$\frac{1}{v_0} = \frac{1}{f_0} + \frac{1}{u_0}$$

$$= \frac{1}{1.25} - \frac{1}{1.5} = \frac{1.5 - 1.25}{1.5 \times 1.25} = \frac{0.25}{1.875}$$

$$\therefore \quad v_0 = \frac{1.875}{0.25} = 7.5 \text{ cm}$$

Now, Magnifying power of the microscope,

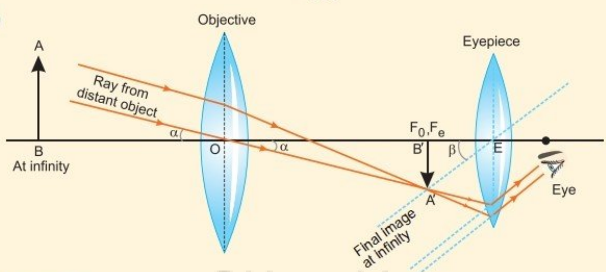
$$M = -\frac{|v_0|}{|u_0|}\left(1 + \frac{D}{fe}\right)$$

$$M = -\frac{7.5}{1.5}\left(1 + \frac{25}{5}\right) = -30$$

Negative sign shows that the image is inverted.

OR

(*b*) (*i*)



In normal adjustment position, for relaxed eye, the final image is formed at infinity.

Magnifying power, $M = \frac{-f_0}{f_e}$

(*ii*) Here, $M=2.9$ [For normal adjustment]

$L = 150$ cm

As we know, $M = \frac{-f_0}{f_e} = 2.9$

$f_0 = 2.9 f_e$ ...(*i*)

And, $L = f_0 + f_e = 150$ ...(*ii*)

From eq (*i*) and (*ii*)

$2.9\, f_e + f_e = 150$

$\therefore f_e = \frac{150}{3.9} = 38.46$ cm

So, $f_o = 2.9\, f_e = 2.9 \times 38.46 = 111.54$ cm

SECTION–E

34. (*i*) No, As from lens maker's formula $f \propto \frac{1}{(n-1)}$ so, different value of n inside the lens having different focal length so, more than one image may be formed.

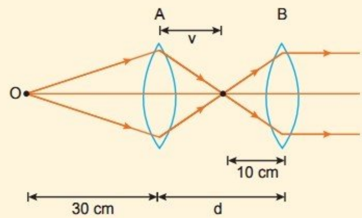
(*ii*) Yes, image will be still formed but it is not observe without screen, because for real image formation, minimum two rays meet on screen at a point after refraction through lens.

(*iii*) From lens maker's formula,

$$\frac{1}{f} = (n-1)\left(\frac{1}{R} + \frac{1}{R}\right)$$

$\therefore R = 2(n-1)\, f = 2(1.55 - 1) \times 20 = 22$ cm

OR



(*iii*) Here, $f_A = 15$ cm, $f_B = 10$cm $u_A = 30$ cm

From lens formula at A,

$$\frac{1}{v_A} - \frac{1}{u_A} = \frac{1}{f_A}$$

$$\frac{1}{v} = \frac{1}{f_A} + \frac{1}{u_A} = \frac{1}{15} - \frac{1}{30} = \frac{2-1}{30} = \frac{1}{30}$$

$\therefore v_A = 30$ cm.

Now, for ray emerging from lens B and parallel to principle axis, after 1st refraction through A, rays must be incident on less B come from their focous (f_B).

Hence, $u_B = f_B = 10$ cm

So, total distance between two lens,

$d = v_A + u_B = 30 + 10 = 40$ cm

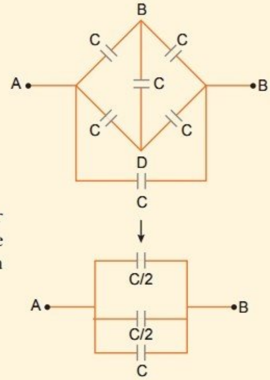
35. (*i*) From circuit shown,

By balance condition of W.S.B,

$$\frac{C}{C} = \frac{C}{C} = 1$$

then, charge flow across A is zero. So,

C of that middle part (BD) part will be neglected.



Now, all capacitance are in parallel

$$C_{AB} = \frac{C}{2}+\frac{C}{2}+C = 2C$$

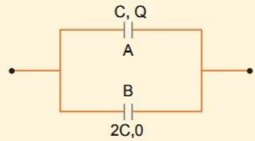
(*ii*) If dielectric slab inserted between plate of capacitor increases and to keep charge constant, potential deffence across plates decreases as results electric field between plates decreases. (*i.e.*, $E = \frac{V}{l}$)

(*iii*) (*a*) Here $C_A = C, Q_A = Q$

and $C_B = 2C, Q_B = 0$

So, Common potential,

$$V_C = \frac{Q_A+Q_B}{C_A+C_B} = \frac{Q}{2C+C} = \frac{Q}{3C}$$



(*b*) Now, new charge on A, $Q_A = C\,V_C$

$$= C \times \frac{Q}{3C} = \frac{Q}{3}$$

So, Charge lost $= Q-\frac{Q}{3} = \frac{2Q}{3}$

OR

(*iii*) The space between its plates is now filled with slabs of dielectric constants $2K$ and K in such a way. So, it behave as capacitors are connected in series.

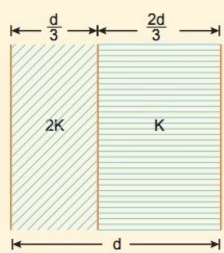
As we know, $C = \frac{A\varepsilon_0}{d}$

So $\frac{1}{C_{eq}} = \frac{1}{C_1}+\frac{1}{C_2}$

$$= \frac{2}{2KC_1}+\frac{1}{KC_2}$$

$$= \frac{1}{2K\left(\frac{A\varepsilon_0}{d/3}\right)}+\frac{1}{K\left(\frac{A\varepsilon_0}{2d/3}\right)}$$

$$= \frac{d}{6KA\varepsilon_0}+\frac{2d}{3KA\varepsilon_0} = \frac{d+4d}{6KA\varepsilon_0} = \frac{5d}{6KA\varepsilon_0}$$



$$\therefore \quad C_{eq} = \frac{6KA\varepsilon_0}{5d}$$

CBSE Practice Paper (Unsolved)

Time allowed: 3 hours **Maximum marks: 70**

General Instructions:

(i) *There are **35** questions in all. **All** questions are compulsory.*

(ii) *This question paper has five sections: **Section A, Section B, Section C, Section D** and **Section E**. All the sections are compulsory.*

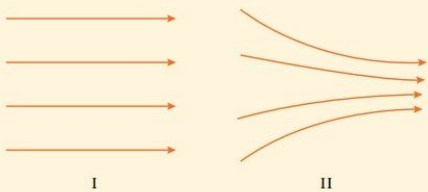
(iii) ***Section A** contains **eighteen MCQ** of **1 mark** each, **Section B** contains **seven questions** of **2 marks** each, **Section C** contains **five questions** of **3 marks** each, **Section D** contains **three long questions** of **5 marks** each and **Section E** contains **two case study based questions** of **4 marks** each*

(iv) *There is no overall choice. However, an internal choice has been provided in **section B, C, D** and **E**. You have to attempt only **one** of the choices in such questions.*

(v) *Use of calculators is not allowed.*

SECTION–A

1. The image below shows two examples of electric field lines. **1**



Which of the following statements is true?

(*a*) The electric fields in both I and II arise due to a single positive point charge located somewhere on the left.

(*b*) The electric fields in both I and II can be created by negative charges located somewhere on the left and positive charges somewhere on the right.

(*c*) The electric field in I is the same everywhere but the electric field in II becomes stronger as we move from left to right.

(*d*) As you move from left to right, the electric fields in both I and II become stronger.

2. The capacitance of a capacitor is C_o. It is connected to a battery of voltage V which charges the capacitor. With the capacitor still connected to the battery, a slab of dielectric material is introduced between the plates of the capacitor. **1**

Which of the following explains the effect of the dielectric slab in the above situation?

(*a*) The electric field between the plates of the capacitor rises.

(*b*) The potential difference between the plates falls.

(*c*) The total charge on the capacitor increases.

(*d*) The ability of the capacitor to store charge decreases.

3. **In a given region, electric potential varies with position as $V(x) = 3 + 2x^2$. Identify which of the following statements is correct.**
   (*a*) Potential difference between the two points $x = 2$ and $x = -2$ is 2 V.
   (*b*) A charge of 1 C placed at $x = 2$ experiences a force of 6 N.
   (*c*) The force experienced by the above charge is along $+ x$-axis.
   (*d*) The electric field in the given region is non-uniform along x-axis.

4. **Two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (A), (B), (C), and (D) as given below.** **1**

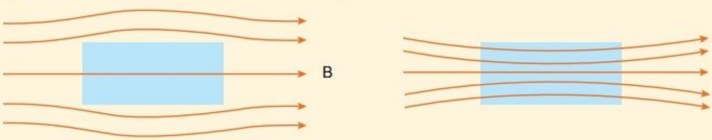
   Assertion (A) : As the temperature of a conducting wire increases, the drift velocity of the electrons also increases.

   Reason (R) : With an increase in temperature, the average time of collision increases.
   (*a*) Both A and R are true and R is the correct explanation of A.
   (*b*) Both A and R are true and R is NOT the correct explanation of A.
   (*c*) A is true but R is false.
   (*d*) A is false and R is also false.

5. **A wire of length L carrying a current I can be turned into a circular loop of N turns. For what value of N, will the magnetic moment of this current-carrying loop be maximum?** **1**
   (*a*) one
   (*b*) $4\pi L$
   (*c*) infinite
   (*d*) Magnetic moment is a constant for a given L and is independent of N.

6. **A deuteron and an alpha particle move with the same kinetic energy under the effect of identical magnetic fields. What will be the ratio of the radii of their paths followed?** **1**
   (*a*) 1 (*b*) $\sqrt{2}$ (*c*) $\frac{1}{2}$ (*d*) 2

7. **Two blocks of different materials are placed in a uniform magnetic field B. The magnetic field lines passing through the two blocks are represented as follows.** **1**



(I) (II)

Identify the suitable values of relative permeability μ_r and magnetic susceptibility χ for the materials I and II.
   (*a*) For I : $\mu_r > 1, \chi < 0$, For II : $\mu_r < 1, \chi > 0$
   (*b*) For I : $\mu_r > 1, \chi < 0$, For II : $\mu_r > 1, \chi > 0$
   (*c*) For I : $\mu_r = 0, \chi < 1$, For II : $\mu_r = 1, \chi > 0$
   (*d*) For I : $\mu_r < 1, \chi < 0$, For II : $\mu_r > 1, \chi > 0$

8. **There is a pair of concentric and coplanar conducting loops of radii R_1 and R_2 such that $R_2 = 0.01\ R_1$. To which of the following is the mutual inductance M for this pair directly proportional?** **1**
   (*a*) $\frac{1}{R_1^2}$ (*b*) $R_1^{\ 2}$ (*c*) $\frac{1}{R_1}$ (*d*) R_1

9. **A 5 ohm resistor, a 5 mH inductor and a 5 μF capacitor, joined in series resonate with an *ac* source of frequency ω_o. If only the resistance is changed to 10 ohm, the circuit resonates at a frequency ω_1. If only the inductor is changed to 20 mH, the circuit resonates at a frequency ω_2. Find the ratio ω_1/ω_2.**
   (*a*) 0.5 (*b*) 1 (*c*) 2 (*d*) 4

10. **Which of the ac circuits with the following input voltage and current dissipates maximum power *P*?** 1

(*a*) Input voltage $V_o = 2$ volt, $I_o = 4$ ampere and phase angle $\Phi = \pi/4$.

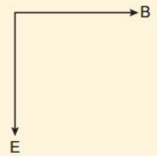
(*b*) Input voltage $V = V_o \sin\omega t$ volt and the current $I = I_o \sin(\omega t - \pi/2)$ ampere

(*c*) Input voltage $V = 2 \cos\omega t$ volt and the current $I = 4 \sin\omega t$ ampere

(*d*) Input voltage $V = 100 \sin 100t$ volt and the current $I = 100 \sin(100t + \pi/3)$ milliampere

11. **The diagram below shows the electric field (*E*) and magnetic field (*B*) components of an electromagnetic wave at a certain time and location.** 1

What is the direction of propagation of the em wave?



(*a*) Perpendicular to *E* and *B* and out of the plane of the paper.

(*a*) Perpendicular to *E* and *B* and into the plane of the paper.

(*a*) Parallel and in the same direction as *E*.

(*a*) Parallel and in the same direction as *B*.

12. **Two statements are given-one labelled Assertion (*A*) and the other labelled Reason (*R*). Select the correct answer to these questions from the codes (*A*), (*B*), (*C*), and (*D*) as given below.** 1

Assertion (*A*) : Interference pattern has all maxima that are equally bright and bands are large in number in comparison to the diffraction pattern that has maxima of decreasing intensity and fewer in number.

Reason (*R*) : Interference is the result of the superposition of the waves from two different wavefronts whereas diffraction is the result of the superposition of the wavelets from different points of the same wavefront.

(*a*) Both *A* and *R* are true and *R* is the correct explanation of *A*.

(*b*) Both *A* and *R* are true and *R* is NOT the correct explanation of *A*.

(*c*) *A* is true but *R* is false.

(*d*) *A* is false and *R* is also false.

13. **Under ideal conditions, consider two different sources of light producing identical waves that happen to be in phase with each other.**

The two sources are placed at the corners of a square. They broadcast waves uniformly in all directions.

Which of the following locations of the two sources will ensure that the waves always produce constructive interference at the center of the square? 1

(*a*) any two corners of the square

(*b*) only the adjacent corners of the square

(*c*) only corners across the diagonal of the square

(*d*) one source at the corner and the other at the center

14. **Given below are two charged subatomic particles *P* and *Q*, that are accelerated through same potential difference *V*. Here, Masses: $m_P = m_Q$ Charges: $\frac{1}{2} q_P = q_Q$**

Which of the two sub atomic particles will have longer de Broglie wavelength? 1

(*a*) Particle *P*, because it has the greater momentum

(*b*) Particle *Q*, because it has the greater momentum

(*c*) Particle *P*, because it has the smaller momentum

(*d*) Particle *Q*, because it has the smaller momentum

15. **Assuming that the momentum of an electron is measured with complete accuracy, that is., the corresponding uncertainty in its momentum being zero, what is the uncertainty in a simultaneous measurement of the electron's position?** 1

(*a*) zero

(*b*) unity

(*c*) infinitely large

(*d*) some finite value between unity and infinity

16. **Each of the statements below are based on the properties of electron orbits in a hydrogen atom. Identify a statement that correctly satisfies the Bohr's model of an atom.** 1

(*a*) The angular momentum of the orbiting electron is $3h/\pi$.

(*b*) The potential energy of the electron in any stable orbit is positive.

(*c*) The radius of the second electron orbit is $2a_0$, where a_0 is Bohr's radius.

(*d*) An amount of energy = –3.4 eV given to an electron in its second orbit will let it escape the atom.

17. **Two statements are given-one labelled Assertion (*A*) and the other labelled Reason (*R*). Select the correct answer to these questions from the codes (*A*), (*B*), (*C*), and (*D*) as given below.** 1

Assertion (*A*) : The curve between the binding energy per nucleon versus mass number droops at high mass numbers ($A > 170$) as well as at low mass numbers ($A < 30$).

Reason (*R*) : Nuclei with middle mass numbers ($30 < A < 170$) have higher binding energy per nucleon.

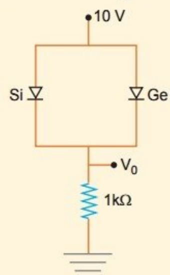
(*a*) Both *A* and *R* are true and *R* is the correct explanation of *A*.

(*b*) Both *A* and *R* are true and *R* is NOT the correct explanation of *A*.

(*c*) *A* is true but *R* is false.

(*d*) *A* is false and *R* is also false.

18. **In an ON state, the individual Silicon and Germanium diodes, allow a voltage drop of 0.7 V and 0.3 V respectively across them. In the circuit shown, the Si and the Ge diode, are connected in a parallel combination to a voltage source of 10V.** 1



What is the voltage V_o for the circuit network?

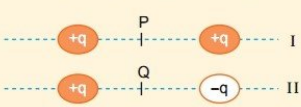
(*a*) 0 volt (*b*) 9.3 volt

(*c*) 9.7 volt (*d*) 10 volt

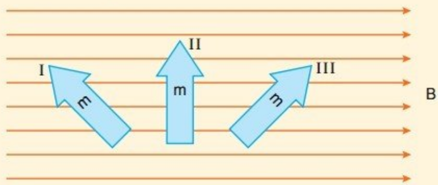
SECTION–B

19. (*a*) If electric field strength at a point is zero at a given point, then what can you say about the electric potential at that point? Explain.

(*b*) In the two instances below, state whether electric field intensity and electric potential are zero or non-zero at the mid-point joining the two-point charges. 2



20. As shown below, a magnetic dipole moment is oriented in 3 different ways in a uniform magnetic field.



(a) Which orientation results in the largest magnetic torque on the dipole?

(b) Which orientation has the largest potential energy? Give a reason for your answer. **2**

21. A capacitor consists of two parallel plates, with an area of cross-section of 0.001 m^2, separated by a distance of 0.0001 m. If the voltage across the plates varies at the rate of 10^8 V/s, determine the value of displacement current through the capacitor. **2**

22. The critical angle for the total internal reflection of diamond in air is 24°. State whether the two statements given here are correct or incorrect. Give a reason for your answer.

(a) The critical angle for total internal reflection of diamond is more than 24° when surrounded by water.

(b) The sparkle of the diamond increases remarkably when placed in water. **2**

23. Estimate the number of dark fringes on the either side of the central maximum that can be produced by diffraction set up with slit of width 5×10^{-6} m and incident light of wavelength 600 nm. **2**

24. By what factor does kinetic and potential energy of an electron in a hydrogen atom change as it moves from $n = 1$ to $n = 3$? **2**

OR

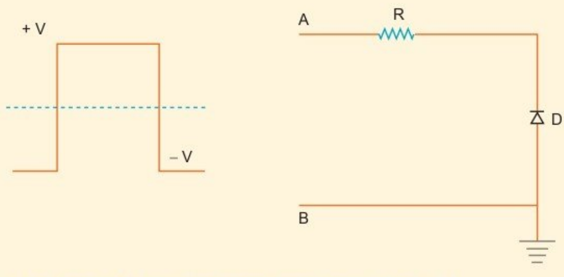
(a) Multiplication factor or reproduction factor K for a nuclear reactor is defined as number of fission reactions produced by a given generation of neutrons to the number of fission reactions in the preceding generation. What should be the value of K for the following purposes?

(i) To keep the nuclear fission reaction self-sustaining

(ii) To switch off the nuclear reactor

(b) Why are moderators more effective in slowing the fast moving neutrons instead of abundant ^{238}U atoms found in the naturally occurring U sample?

25. In the circuit containing an ideal PN diode D and a resistor R is given an input square wave as shown.

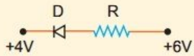


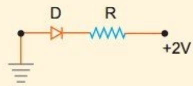
(a) What is the shape of the output waveform across diode D?

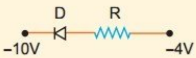
(b) Give an explanation for your answer in (a). **2**

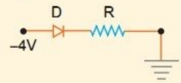
OR

Categorize each of the following junction diodes as either forward biased or reverse biased. Give reason for each answer.

(*a*) 

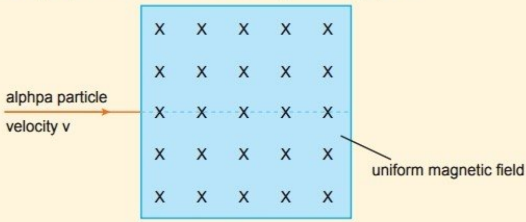
(*b*) 

(*c*) 

(*d*) 

SECTION–C

26. An alpha particle is moving with a velocity v. It enters a magnetic field (B) as shown below. The magnetic field is perpendicular and into the plane of paper.



A uniform electric field is applied in the same region as the magnetic field so that the alpha particle passes undeviated through the combined fields.

(*a*) What should be the direction of the electric field?

(*b*) Without any change in the electric and magnetic field, the alpha particle is replaced by the following particles:

(*i*) proton moving with a velocity v

(*ii*) electron moving with a velocity $\frac{v}{2}$ **3**

Will there be any change a deviation in the path of the particles? Give a reason for your answer.

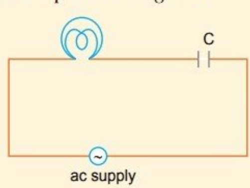
27. Coil 1 has self-inductance L_1 which is 3 times the self-inductance L_2 of coil 2. If during a certain instant, the rate of increase in current and the power dissipated in these two coils is the same, then determine the ratio of

(*a*) their induced voltages

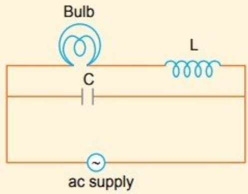
(*b*) currents

(*c*) energy stored in the two coils at that instant. **3**

28. A bulb is connected through a capacitor in an *ac* circuit as in the circuit (*i*). The bulb in the circuit glows when the frequency of the input ac voltage is ω.



A circuit (*ii*) is constructed by including an inductor L as shown, keeping all other components the same as in circuit (*i*). The bulb continues to glow when the frequency of the input *ac* voltage is ω.



Now the frequency ω of the *ac* supply is changed in both the circuits while keeping the voltage amplitude constant and same in both the circuits. Explain the effect on the brightness of the bulb in each circuit if

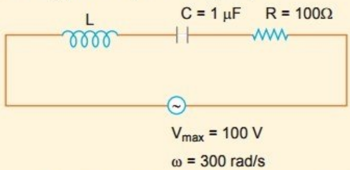
(*a*) the frequency of input *ac* voltage is lowered

(*b*) the frequency of input *ac* voltage is increased

(*c*) the frequency of input *ac* voltage approaches zero. **3**

OR

A series *LCR* circuit as shown in the diagram is connected to an input ac voltage. The voltage across the capacitor lags the applied input voltage by 45°.



(*a*) Represent the phase relationship for the voltages across the three elements *L*, *C* and *R* using a phasor diagram.

(*b*) Determine the phase angle Φ in the given circuit.

(*c*) Determine the value of inductor *L*.

29. (*a*) Mention one proposition that is predicted as per wave theory of light but discarded on the basis of the actual experimental observation in the phenomenon of photoelectric emission.

(*b*) A cat is able to see in low light intensity situations by virtue of its large sized pupils of diameter ~ 16 mm and due to the presence of excess number of cone cells on its retina. They can detect light of intensity *I* as low as ~ 10^{-10} W/m^2.

If intensity *I* of light is defined as energy of radiation times the number of photons per unit area, then determine the minimum number of incident photons per second of wavelength 600 nm that are required in a radiation to be detected by a cat's eye?

Take $hc \sim 2 \times 10^{-16}$ J–nm. **3**

OR

(*a*) Give reason: A radiation of wavelength $\lambda < \lambda_{threshold}$ incident on a metal sphere placed on an insulated stand results in the emission of photoelectrons for some time and then stops.

(*b*) In the photoelectric experiment apparatus containing the collector and the emitter plate, a saturated photoelectron current is observed. If an external electric field is applied in the direction opposite to the motion of the photoelectrons, what is the change observed in each of the following? Give reasons.

(*i*) The saturation value of the photocurrent.

(*ii*) The kinetic energy of the photoelectrons striking the collector plate.

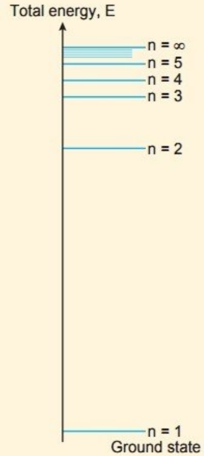
30. (*a*) A glass container contains hydrogen atoms with all its atoms in their ground states. The container is irradiated with electromagnetic waves containing wavelengths corresponding to

Lyman, Balmer and Paschen series. The electromagnetic waves exiting the glass container are found to have certain strong absorption spectral lines. Identify one or more series to which these absorption spectral lines would correspond to. Explain. Assume that once an electron absorbs a photon and jumps to a higher level, it does not absorb more photons to jump to even higher levels.

(*b*) An electron in its orbit undergoes transitions across the energy levels either by absorbing or emitting the photons. A given hydrogen atom is in third excited state. Determine the final quantum number and the energy of the photon,

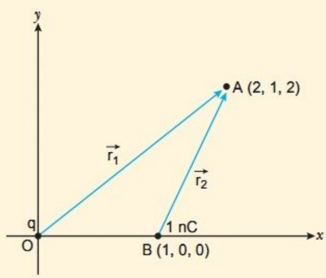
(*i*) when a photon with shortest wavelength is emitted.

(*ii*) when a photon with longest wavelength is absorbed. **3**

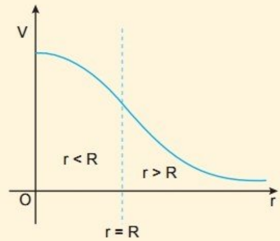


SECTION–D

31. (*a*) An unknown charge q is placed at the origin and another charge of 1 nC is placed at position $B(1, 0, 0)$. The x- component of the electric field due to these two charges at position $A(2, 1, 2)$ is zero. Determine charge q.



(*b*) A given solid sphere of radius R made of an insulating material carries a charge q distributed uniformly throughout its volume. The potential due to this charge distribution as a function of distance r from the center of the sphere is given as:



(*i*) At which location with respect to the sphere, is the potential V maximum in this case?

(*ii*) In case the above sphere is made up of a conducting material instead of an insulating material, what would be your answer for part (*a*)? How is the charge q distributed across a charged conducting sphere? **5**

OR

A parallel plate capacitor of capacitance C is charged to a potential V by a battery. Q is the charge stored on the capacitor. Without disconnecting the battery, the plates of the capacitor are pulled apart to a larger distance of separation.

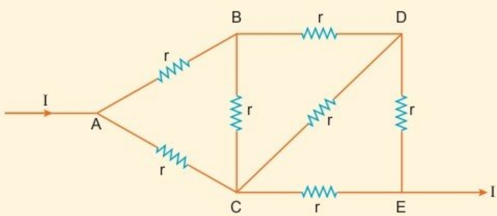
What changes will occur in each of the following quantities? Will they increase, decrease or remain the same? Give an explanation in each case.

(*a*) Capacitance (*b*) Charge

(*c*) Potential difference (*d*) Electric field

(*e*) Energy stored in the capacitor

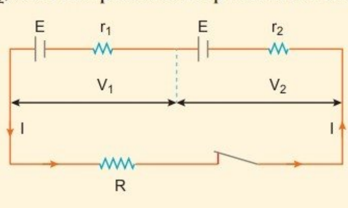
32. (*a*) In the circuit given below if I is the current entering the network of resistors of equal resistances,



(*i*) Using Kirchhoff's rules, prove that current through the arm AC is equal to that in the arm CE. Show the distribution of the current diagrammatically.

(*ii*) Redraw the diagram to show the split in junction C without altering the current in any arm.

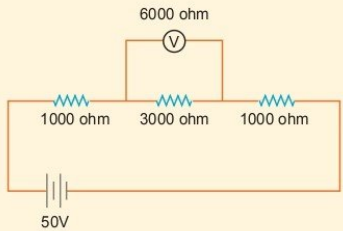
(*b*) In the circuit of two cells, each of emf E but different internal resistances are connected in series as shown in the diagram. Determine the external resistance R in terms of internals resistances r_1 and r_2, such that potential drop across the cell E_1 is zero.



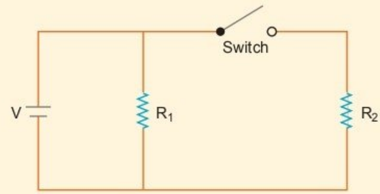
5

OR

(*a*) In the given *dc* circuit, a voltmeter whose resistance is 6000 ohm is used to measure the voltage drop across the 3000 ohm resistor. Determine the % difference in the voltmeter reading that is observed when compared to the true voltage across 3000 ohm resistor when the voltmeter is not connected.



(*b*) In the circuit diagram, consider $R_1 = r$, $R_2 = 2r$ and power supply of voltage V:



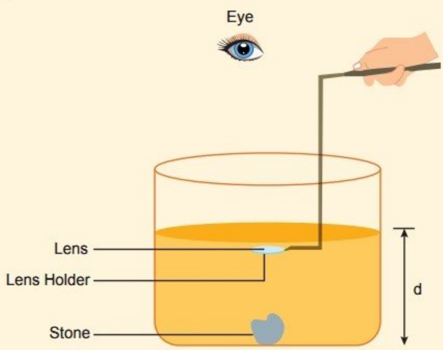
Determine the power consumed by the circuit in each of the following instances:

(*i*) when the switch is open

(*ii*) when the switch is closed

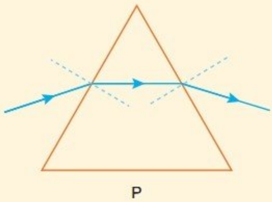
(*iii*) while the switch is closed, the resistor R_2 is heated so that its resistance is doubled.

33. (*a*) In reference to the picture given here, a convex lens of focal length *f*(in air), is immersed in the water to view a small black stone that is placed at the bottom of the container is at a depth *d* from the lens.



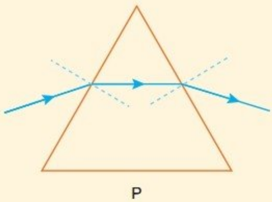
Will the stone in the water be visible as seen from above, for $d = f$ or $d < f$ or $d > f$? Give reason for your answer.

(*b*) In the given combination of three triangular prisms, a ray of light enters the first prism on the left and exits from prism on the right after refraction. Consider the angles of the prisms to be small and the ratio $A_o/A = 2$.



Prove that for a net deviation produced in the light ray to be zero, $\mu = \mu_o$ in the given combination.

(*c*) A glass prism of absolute refractive index of 1.52 is surrounded by a medium. The emergent rays are bent either upwards or downwards.



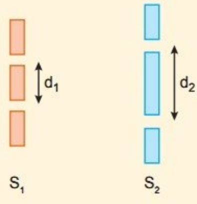
Select the suitable surrounding mediums from the given table of refractive indices here for each of the above refractions through the prisms P and Q. Give reason for the choice of the mediums. **5**

Medium	Refractive index
Benzene	1.50
Carbon disulphide	1.63
Ethyl alcohol	1.36
Aqueous sodium chloride	1.54

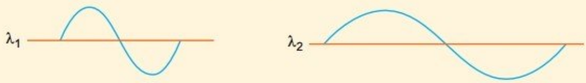
OR

(*a*) The interference pattern due to light shows bright and dark regions that appear similar to the antinodes and nodes of a standing-wave pattern on a string. While both the patterns are based on the superposition principle, give one major point of difference between the standing waves pattern and the interference pattern.

(*b*) Given two sets of slits S_1 and S_2.



Also given are two possible incident light wavelengths λ1 and λ2.



State with reason for what combination of the slits and wavelengths will the interference pattern be:

(*i*) most spread out

(*ii*) least spread out?

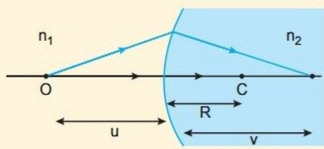
(*c*) Determine the value of y at which the intensity of the fringe reduced to half the intensity of the central maxima formed at point O.

SECTION–E

34. Case study: Refraction

Refraction at a curved refracting surface of radius of curvature R is governed by curved surface formula that is given as

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R} \qquad ...(i)$$



For a plane refracting surface, the curved surface formula gets modified as: $n_2/v = n_1/u$ .....(*ii*)

Consider a bird flying vertically downwards towards a fish inside the pond on the ground. At a given instant, if the true height of the bird is x from the plane surface of water, the bird will appear at a height y as seen by the fish in the water due to refraction of light through the plane air-water interface.

Also if the bird is flying down through a height x in time t, the fish will see the bird fall through a height y in the same time t. **4**

(*a*) Show how equation (1) gets modified to equation (2) for a plane refracting surfaces.

(*b*) Use this modified surface formula for a plane refracting surface, in order to determine if, $x = y$, or $x < y$ or $x > y$, for the fish in the water looking at the bird in the air.

(*c*) Draw a ray diagram to show the position of the bird at a height y as seen by the fish in the water. Confirm the result obtained in (*b*) diagrammatically.

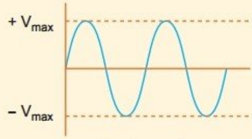
OR

Draw a diagram to show how the bird in the air sees the fish in the water. Is it near or farther from the surface of water as compared to the true depth *d*?

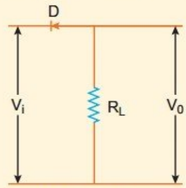
(*d*) Does the fish see the bird flying towards it at a speed greater or lesser than the true speed? Justify the answer qualitatively only.

35. Case study: Clipper circuits

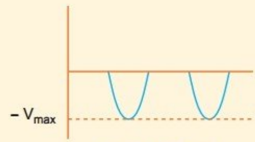
A half wave rectifier circuit is also known as a clipper. A clipper circuit removes either the positive half or negative half or a part of the input positive or negative cycles of the input AC signal. In a typical half wave rectifier circuit, as shown in the circuit diagram, only the positive half cycles are completely removed. This circuit is also known as the Series Positive Clipper.



Input waveform

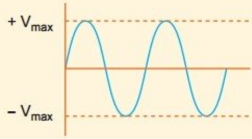


Series positive clipper

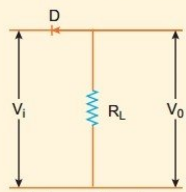


Output waveform

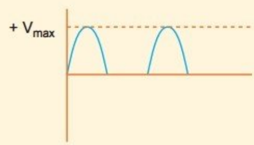
Similarly, just by reversing the diode, only the negative half cycles are removed. This is Series Negative Clipper circuit.



Input waveform

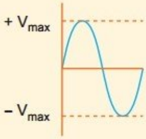


Series positive clipper

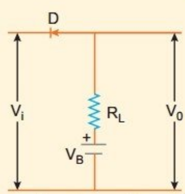


Output waveform

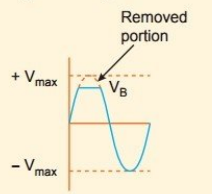
Now a Series Positive Clipper circuit can be modified by including a battery as shown here.



Input waveform



Series positive clipper with positive bias



Output waveform

During the positive input half cycle, the diode is reverse biased by the input supply voltage V_i. But since the positive terminal of the battery is connected to *p*-side and the negative terminal of the battery is connected to *n*-side of the diode, the diode is forward biased by the battery voltage V_B.

That means the diode is reverse biased by the input supply voltage (V_i) and forward biased by the battery voltage (V_B). Initially, the input supply voltage $V_i < V_B$, so V_B dominates over the V_i. Hence, the diode is forward biased by the V_B and allows electric current through it. As a result, the signal appears at the output.

As soon as V_i becomes greater than V_B, the diode is reverse biased. So no current flows through the diode.

As a result, input signal does not appear at the output. Instead a constant voltage = V_B appears across the output. So the clipping takes place during the positive half cycle, at the time the input V_i is greater than the V_B. Now consider the negative input half cycle. The diode is forward biased by both V_B and V_i. That means, during the negative half cycle, it doesn't matter whether the V_i is greater or less than the V_B, the diode remains forward biased. So the complete negative half cycle appears at the output. Thus, the series positive clipper with positive bias clips a small portion of the positive half cycles in the output. **4**

Answer the following questions:

(*a*) Draw the circuit diagram to represent the series clipper circuit with a negative bias.

(*b*) Which part of the input ac cycle will get clipped in the case of series clipper circuit with a negative bias? Represent the clipped output waveform through this circuit.

(*c*) Explain the output waveform during the positive input cycle in the series clipper circuit with a negative bias.

OR

Explain the output waveform during the negative input cycle in the series clipper circuit with a negative bias.

ANSWERS

1. (*c*) **2.** (*c*) **3.** (*d*) **4.** (*d*) **5.** (*a*) **6.** (*b*) **7.** (*d*) **8.** (*d*) **9.** (*c*) **10.** (*a*)
11. (*a*) **12.** (*a*) **13.** (*a*) **14.** (*d*) **15.** (*c*) **16.** (*a*) **17.** (*b*) **18.** (*c*)

21. 8.8 mA **23.** 8 **27.** (*a*) 3 (*b*) $\frac{1}{3}$ (*c*) $\frac{1}{3}$ **28.** **OR** (*b*) –45° (*c*) 10.7 H

29. (*b*) 6028 photons/second **30.** (*i*) $n = 1$, 12.75 eV (*ii*) $n = 5$, 0.31 eV

31. –0.9 nC **32.** (*ii*) $r_1 - r_2$ **OR** (*a*) 16.6% (decrease)