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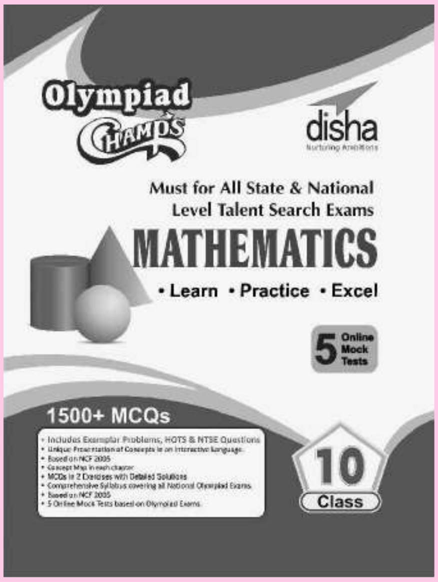
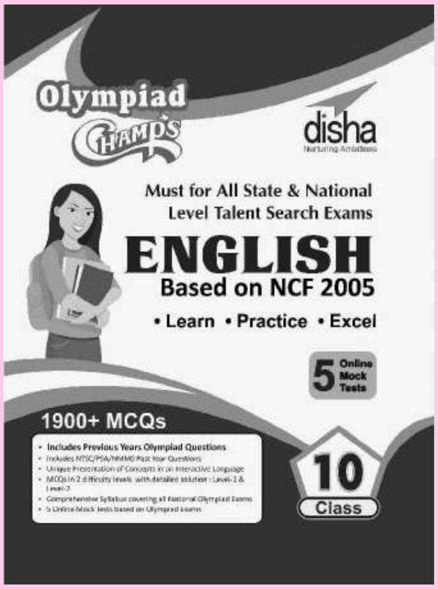
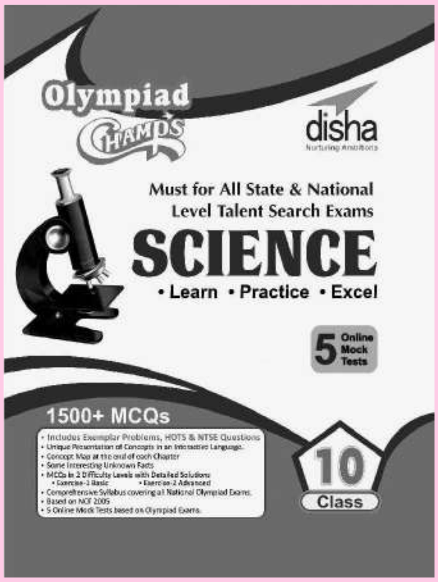






Chapter 1

LIGHT-REFLECTION AND REFRACTION

INTRODUCTION

Light is a form of energy which enables human beings and creatures to 'see' things. When light emitted from an object or reflected from the object enters our eyes, we are able to see the object. We cannot see an object in dark even if we are in light because there is no light coming from the object to our eyes.

Any object that is not giving of its own light may be seen only when the following conditions are there.

- The object must have in its surrounding a source of light as object itself not emiting light.
- The light from the source must strike the object.
- The light must be reflected from the object to the eye.

Light is an electromagnetic radiation which exhibits properties like a wave as well as a particle. It always propagates in a straight line and reflects, refracts or shows total internal reflection at an interface separating two media in different conditions. This chapter is an attempt to provide sufficient information to make us understand what is light, how does it propagate, how does it show reflection, refraction and total internal reflection, how does it behave with mirrors and lenses, etc.

WHAT IS LIGHT ?

Light is a form of energy that produces the sensation of vision on our eyes.

It is an electromagnetic radiation, such as that emitted by the Sun, which acts like a wave in a frequency range that the human eye can perceive. At the same time, light also acts like a stream of particles, which are called photons (hence the expression “beam of light”). Electrons can be shot out of atoms and molecules can be split simply by the impact of a photon striking them. A film in a camera is exposed in this way; the light splits the silver bromide into silver and bromine. The silver darkens the film and a negative is created. Light is a combination of electric and magnetic oscillations in mutually perpendicular directions as shown in Fig.1. But the light wave itself propagates in a direction perpendicular to both the oscillations.
The branch of physics which deals with nature, source, properties and the effects of light is callcd **optics.**

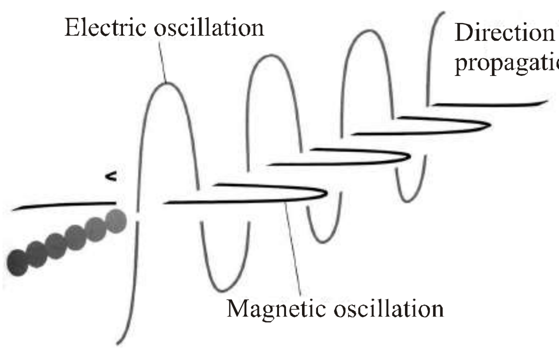


Fig. 1.1 Electric and magnetic oscillations are mutually perpendicular.
The light wave propagates in a direction perpendicular to both.

CHARACTERISTICS OF LIGHT

(1) Light travels along a straight line in a medium or vacuum. The path of light changes only when the medium changes. This is also called the **rectilinear propagation of light.** The casting of shadows and eclipses are due to the rectilinear propagation of light.
(2) Light travels with a speed nearly equal to 3×10^8 m/s. i.e. the speed of light in vacuum. According to current theories, no material particle can travel at a speed greater than the speed of light.
(3) The speed of light waves depends on the medium through which they pass.
(4) Light shows different behaviour such as reflection, refraction, interference, diffraction, polarisation etc. some of which we will deal with subsequently in this book and some in higher classes.

RAY AND BEAM OF LIGHT

Let us consider a source of light(s). Also consider the light which passes from the point A to the point B in a medium.
Actually, the light passes through all the points of the straight line AB. Such a straight line path AB is called a **ray of light**, generally represented by a directed arrow (→).

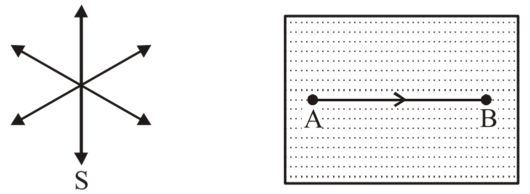


Fig. 1.2 AB is a ray of light in a medium

Fig. 1.3 A parallel beam of light.

A small bundle of these rays is called a **pencil of rays** and large bundles of these rays is called a **beam of light**.
A bundle of rays in which rays are parallel to one another is called parallel beam of light.

REFLECTION OF LIGHT

Most of the things we see around us do not emit their own light. They are visible because they reemit light reaching their surface from a primary source, such as the sun or a lamp, or from a secondary source, such as the illuminated sky. When light falls on the surface of a material, it is usually either reemitted without change in frequency or is absorbed into the material and turned into heat. Usually, both of these processes occur in varying, degrees. When the reemitted light is returned into the medium from which it came, it is *reflected*, and the process is referred to as **reflection**. i.e. *the turning back of light in the same medium is called reflection of light.*

When this page is illuminated by sunlight or lamplight, electrons in the atoms of the paper vibrate more energetically in response to the oscillating electric fields of the illuminating light. The energized electrons reemit the light by which we see the page. When the page is illuminated by white light, it appears white, which reveals the fact that the electrons reemit all the visible frequencies. Very little absorption occurs. The ink on the page is a different story. Except for a bit of reflection, the ink absorbs all the visible frequencies and therefore appears black.

CHECK Point

A person in a dark room looking through a window can clearly see a person outside in the daylight, whereas the person outside cannot see the person inside. Explain.

SOLUTION

When a person inside a darkroom is looking through a window to another person outside in broad daylight, then enough re-flected rays come inside to the eye of the observer from the person outside. So he can be seen clearly. But if the person in daylight, looks through the same window to the person inside the dark room, there is hardly any reflected rays coming from the body of the person inside the dark room to the eyes of the observer outside. So the outside observer can't see the person inside the room.

LAWS OF REFLECTION

Anyone who has played pool or billiards knows that, when a ball bounces from a surface, the angle of incidence is equal to the angle of rebound. The same is true of light. This is the **law** of **reflection**, and it holds for all angles:

The law of reflection is illustrated with arrows representing light rays in Fig. 1.4 Instead of measuring the angles of incident and reflected rays from the reflecting surface, it is customary to measure them from a line perpendicular to the plane of the reflecting surface. This imaginary line is called the **normal**. The incident ray, the normal, and the reflected ray all lie in the same plane.

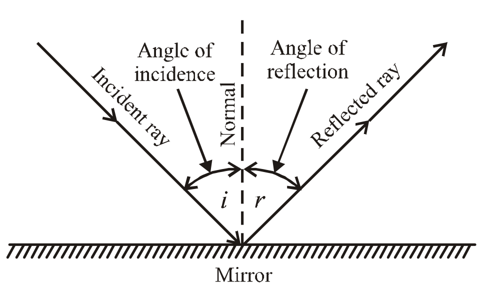


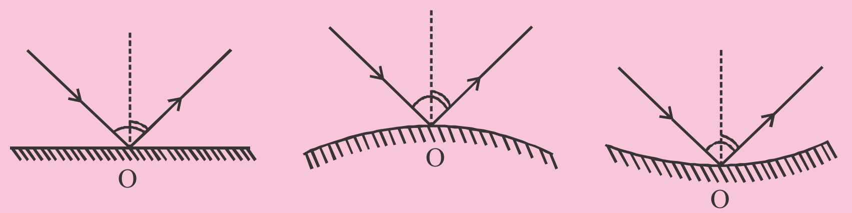
Fig.1.4 The incident ray, the reflected ray, and the normal all lie in the same plane & $\angle i = \angle r$

So, we can summarise the laws of reflection as below :

1. *The angle of incidence* (i) *is always equal to the angle of reflection* (r), *i.e.,* $\angle i = \angle r$
2. *The incident ray, the normal, and the reflected ray all lie in the same plane.*

Knowledge ENHANCER

1. Laws of reflection are applicable for plane surfaces as well as curved surfaces.



(a) (b) (c)
Plane surface Curved surfaces

2. Most people are surprised by the fact that light can be reflected back from a less dense medium. For instance, if you are diving and you look up at the surface of the water, you will see a reflection of yourself.

CHECK Point

Each of these diagrams numbered 1, 2 and 3 is supposed to show two different rays being reflected from the same point on the same mirror. Which are correct, and which are incorrect ?

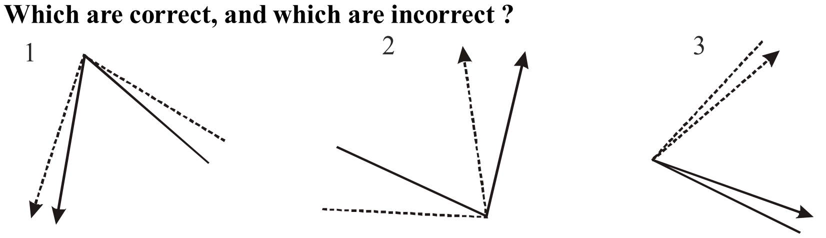


Fig. 1.5

SOLUTION

Only 1 is correct. Draw the normal that bisects the solid ray, it also bisects the dashed ray.

REGULAR AND DIFFUSE REFLECTION

When light is incident on a smooth surface it is reflected in the first medium. This reflection on a smooth surface is called **regular reflection.** When light is incident on a rough surface, it is reflected in many directions. This is called **diffuse reflection.**

(a) Regular re?ection

(b) diffuse re?ection although re?ection of each single ray obeys the law of re?ection, the many different surface angles that light rays encounter in striking a rough surface produce re?ection in many direction.

Fig. 1.6

If the surface is so smooth that the distances between successive elevations on the surface are less than about one-eighth the wavelength of the light, there is very little diffuse reflection, and the surface is said to be *polished*. A surface therefore may be polished for radiation of long wavelengths but rough for light of short wavelengths. The wire-mesh “dish” shown in fig. is very rough for light waves and is hardly mirror like. But, for long-wavelength radio waves, it is “polished” and is an excellent reflector.

Light reflecting from this page is diffuse. The page may be smooth to a radio wave, but, to a light wave, it is rough. Smoothness is relative to the wavelength of the illuminating waves. Rays of light striking this page encounter millions of tiny flat surfaces facing in all directions. The incident light, therefore, is reflected in all directions.

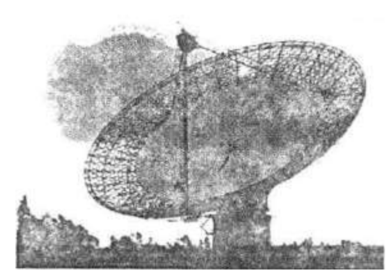


Fig. 1.7 The open-mesh parabolic dish is a diffuse reflector for short-wavelength light but a polished reflector for long-wavelength radio waves.

This is a desirable circumstance. It enables us to see objects from any direction or position. You can see the road ahead of your car at night, for instance because of diffuse reflection by the rough road surface. When the road is wet, however, it is smoother with less diffuse reflection, and therefore more difficult to see. Most of our environment is seen by diffuse reflection.

CHECK Point

An observer on the west-facing beach of a large lake is watching the beginning of a sunset. The water is very smooth except for some areas with small ripples. The observer notices that some areas of the water appear blue and some appear pink. Why does the water appear to be different colors in different areas?

SOLUTION

The different colors arise from specular and diffuse reflection. The smooth areas of the water specularly reflect the light from the west, which is the pink light from the sunset. The areas with small ripples reflect the light diffusely. Thus, light from all parts of the sky is reflected into the observers' eyes. Because most of the sky is still blue at the beginning of the sunset, these areas appear to be blue.

ILLUSTRATION : 1.1

Two mirrors make an angle of 120º with each other as in Fig. 1.8, A ray is incident on mirror M_1 at an angle of 65º to the normal. Find the direction of the ray after it is reflected from mirror M_2.

SOLUTION :

From the law of reflection, we know that the first reflected ray also makes an angle of 65º with the normal. Thus, this ray makes an angle of 90º – 65º, or 25º, with the horizontal. We build the geometric model triangle shown in Figure 1.8 from the triangle made by the first reflected ray and the two mirrors. The first reflected ray makes an angle of 35º with M_2 (because the sum of the interior angles of any triangle is 180º). This means that this ray makes an angle of 55º with the normal to M_2. Hence, from the law of reflection, the second reflected ray makes an angle of 55º with the normal to M_2.

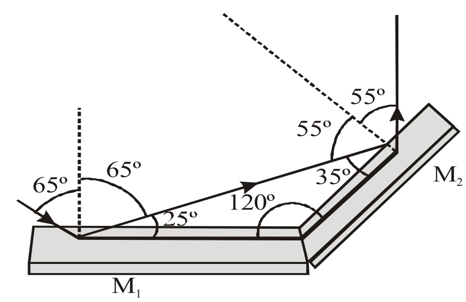


Fig. 1.8 Mirrors M_1 and M_2 make an angle of 120° with each other.

CONNECTING TOPIC

REVERSIBILITY OF LIGHT RAYS

The fact that specular reflection displays equal angles of incidence and reflection means that there is a symmetry: if the ray had come in from the right instead of the left in the figure above, the angles would have looked exactly the same. This is not just a pointless detail about specular reflection.

It's a manifestation of a very deep and important fact about nature, which is that the laws of physics do not distinguish between past and future. Cannonballs and planets have trajectories that are equally natural in reverse, and so do light rays. This type of symmetry is called time-reversal symmetry. Typically, time-reversal symmetry is a characteristic of any process that does not involve heat. For instance, the planets do not experience any friction as they travel through empty space, so there is no frictional heating.

We should thus expect the time-reversed versions of their orbits to obey the laws of physics, which they do. In contrast, a book sliding across a table does generate heat from friction as it slows down, and it is therefore not surprising that this type of motion does not appear to obey time-reversal symmetry. A book lying still on a flat table is never observed to spontaneously start sliding, sucking up heat energy and transforming it into kinetic energy.

Similarly, the only situation we've observed so far where light does not obey time-reversal symmetry is absorption, which involves heat. Your skin absorbs visible light from the sun and heats up, but we never observe people's skin to glow, converting heat energy into visible light. People's skin does glow in infrared light, but that doesn't mean the situation is symmetric. Even if you absorb infrared, you don't emit visible light, because your skin isn't hot enough to glow in the visible spectrum.

REFLECTION AT A PLANE MIRROR

Plane mirror is a looking glass which is highly polished on one surface and silvered on the other surface. The images formed by mirrors are the most common examples of images formed by reflection.

Characteristics of Image Formed by Plane Mirror

1. A plane mirror forms virtual and erect image of the object.
2. Distance of object from mirror = Distance of image from mirror.
3. The image is laterally inverted (better word perversion). i.e., the left of the object becomes the right of the image and vice versa.
4. The line joining the object point with its image is normal to the reflecting surface.
5. The size of the image is the same as that of the object.

Keep in Memory

(i) For a real object the image is virtual and for a virtual object the image is real.

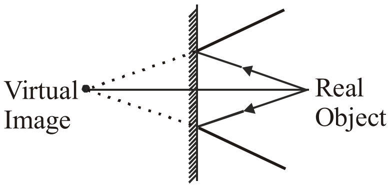


Fig. 1.9 (a)

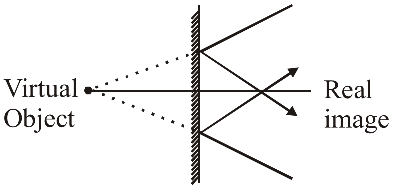


Fig. 1.9 (b)

(ii) If keeping the incident ray fixed, the mirror is rotated by an angle θ, about an axis in the plane of mirror, the reflected ray is rotated through an angle 2θ.

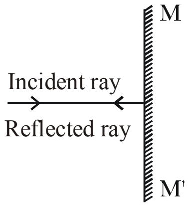


Fig. 1.10 (a)

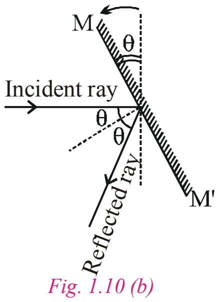


Fig. 1.10 (b)

Knowledge ENHANCER

1. If two plane mirrors are kept inclined to each other at angle θ with their reflecting surfaces facing each other, multiple reflection takes place and more than one images are formed. Number of images (n) for $\theta \le 180°$ are given by :

   (i) $n = \left(\frac{360°}{\theta} - 1\right)$ where $\frac{360°}{\theta}$ is an integer.

   (ii) n = integral part of $\frac{360°}{\theta}$, when $\frac{360°}{\theta}$ is not an integer.

(a) If an object is placed between two parallel mirrors ($\theta = 0°$), the number of images formed will be $(360/0) = \infty$ but of decreasing intensity in accordance with $I \propto (1/r^2)$.

(b) The number of images formed by two mutually perpendicular mirrors $(\theta = 90°)$ will be 3. All these three images will lie on a circle with centre at C – the point of interesection of mirrors M_1 and M_2 and whose radius is equal to the distance between C and object O.

(c) Two mirrors inclined to each other at different angles may provide same number of images, e.g., for any value of θ between 90° and 120° the number of maximum images formed (n) is 3. This in turn implies that if θ is given, n is unique but if n is given, θ is not unique.

(d) The number of images seen may be different from the number of images formed and depends on the position of observer relative to object and mirrors – e.g., if $\theta = 120°$ maximum number of images formed will be 3 (object not on bisector) but no. of images seen can only be 1, 2 or 3 depending on the position of observer.

2. If an object moves towards (or away from) a plane mirror at speed v, the image will also approach (or recede) at same speed v, i.e., the speed of image relative to object will be $v - (-v) = 2v$. Similarly if the mirror is moved towards (or away from) the object with a speed v the image will move towards (or away from the object with a speed $2v$.

3. To locate the image of an object from an inclined mirror, see the perpendicular distance of the object from the mirror.

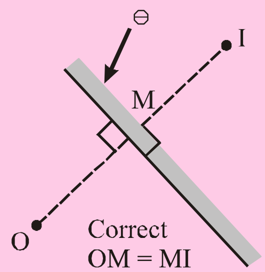


Fig. 1.11 (a)

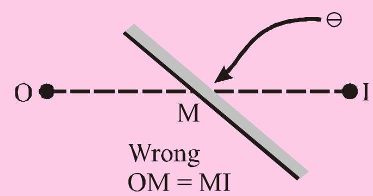


Fig. 1.11 (b)

4. If angle between two mirrors is θ after consecutive reflection total deviation $\delta = \delta_1 + \delta_2 = 2\pi - 2\theta$

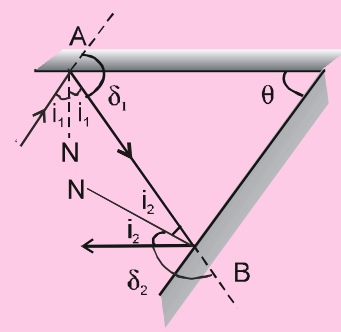


Fig. 1.12

CHECK Point

We see the bird and its reflection. Why do we not see the bird's feet in the reflection?


Fig. 1.13

SOLUTION

The bird's feet are on the reflecting surface so the image of feet is formed at the same place where actually the feet are. So the image of the feet cannot be distinguished from the actual feet. This is so because the distance of the object from the reflecting surface is equal to that of the image from same surface.

ILLUSTRATION : 1.2

Find the minimum height of a plane mirror where one can see his full image.

SOLUTION :

Let HL be the height of the person and E, the position of his eyes. Now applying laws of reflection,

we have, $M'L' = \frac{1}{2}EL$ and $MH' = \frac{1}{2}HE$

Now, $H'L' = MM' - MH' - L'M'$

$= \text{HL} - \frac{1}{2}\text{ EL} - \frac{1}{2}\text{ HE} = \text{HL} - \frac{1}{2}\text{ HL} = \frac{1}{2}\text{ HC}$

So the required height of the mirror be half of the height of the person.

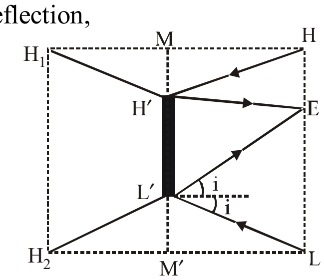


Fig. 1.14

ILLUSTRATION : 1.3

Two plane mirrors are inclined at an angle θ. A ray of light is incident on one mirror at an angle of incidence i. The ray is reflected from this mirror, falls on the second mirror from where it is reflected parallel to the first mirror. What is the value of i, the angle of incidence in term of θ ?

SOLUTION :

The situation is illustrated in fig. 1.19. XA is the incident ray. BC is the final reflected ray. It is given that BC is parallel to mirror M_1. Look at the assignment of the angles carefully. Now N_2 is normal to mirror M_2.

Therefore $\beta = \theta$

Then from $\Delta\ OAB$, $\theta + \beta + 90^\circ - i = 180^\circ$

or $\theta + \theta + 90^\circ - i = 180^\circ$ or $i = 2\theta - 90^\circ$

Thus if the angle of incidence is $i = 2\theta - 90^\circ$, then the final reflected ray will be parallel to the first mirror.

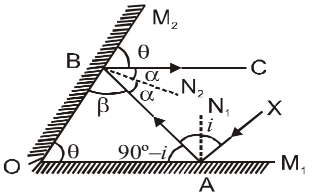


Fig. 1.15

ILLUSTRATION : 1.4

Find the x and y co-ordinates, of the image of a point A (2, 0). MN is a plane mirror.

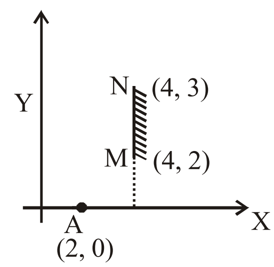


Fig. 1.16

SOLUTION :

Image of A will be at $A'(6, 0)$. Perpendicular distance of image from plane mirror = perpendicular distance of object from plane mirror.

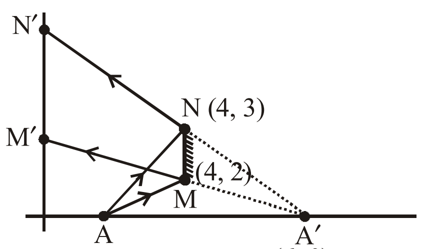


Fig. 1.17

SPHERICAL MIRRORS

A highly polished curved surface whose reflecting surface is a cut part of a hollow sphere of a glass or any polished metal is called spherical mirror. Spherical mirrors are of two types:

Concave Mirrors

Imagine a **sphere** of **hollow** glass. If we cut out a spherical cap and polished it with silver on the outside, we have a **concave mirror** if we look at it from the hollow side. These mirrors, which are referred to as **convergent** mirrors, concentrate the light rays, causing them to arrive parallel to the main axis onto a point known as the **focal point**. Concave mirrors form **real images** that can be **projected** onto a screen if the object is farther away than the focal point. The image obtained is large if formed near the focal point or small if formed far away from the focal point. In both cases, the image is **reversed**. If we place the object closer than the focal point, the image is formed upright and large but virtual (i.e., it cannot be projected).

Convex Mirrors

If we polished the **inner surface** of a concave mirror with silver and look at it toward the **outward bulge**, we have a **convex** mirror. Mirrors of this type are also called **divergent** mirrors because the light beams that reach their surface and are **parallel** to their main axis are diverted in such a way that they **separate**, but their **extensions** come back together again in a point known as the **focal point**. The images produced by a convex mirror are always **virtual, upright**, and **small**.

TERMS RELATED TO SPHERICAL

Centre of curvature (C) **:** It is the centre of sphere of which the mirror is a part.
Radius of curvature (R) **:** It is the radius of the sphere of which the mirror is a part.
Pole (P) **:** It is the geometrical centre of the spherical reflecting surface.
Principal axis : It is the straight line joining the centre of curvature to the pole.
Focus (F) **:** When a narrow beam of rays of light, parallel to the principal axis and close to it (know as paraxial rays), is incident on the surface of a mirror, the reflected beam is found to converge (concave mirror) or appear to diverge (convex mirror) from a point principal axis. This point is called focus.
Focal length (f) : It is the distance between the pole and the principal focus. For spherical mirrors, $f = R/2$.

RULES FOR RAY DIAGRAMS

(i) A ray, parallel to the principal axis will after reflection, pass through the focus. Fig. 1.18 (a), and (b)

Fig. 1.18

(ii) When a ray falls in the direction of centre of curvature of mirror then it reflects back along the same path. Fig. 1.19(a) and (b)

Fig. 1.19

(iii) A ray, passing through the focus is reflected parallel to the principal axis. Fig. 1.20(a), and (b)

Fig. 1.20

REFLECTION THROUGH CONCAVE MIRROR

$F \rightarrow$ Principal focus $\quad$ $P \rightarrow$ Pole of mirror
$C \rightarrow$ Centre of curvature $\quad$ PC = Radius of curvature
PF = Focal length
When a narrow beam of light travelling parallel to the principal axis is incident on the reflecting surface of the concave mirror, the beam after reflection converge at a point on the principal axis.

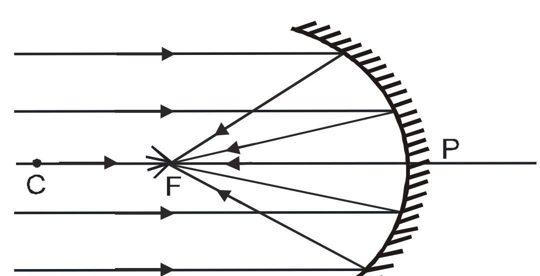
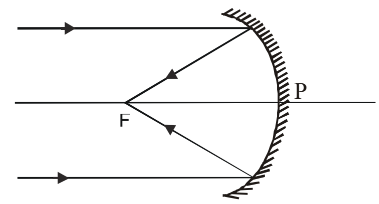
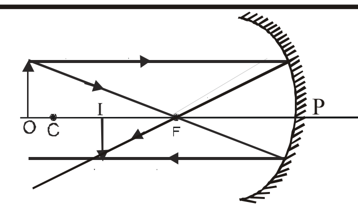
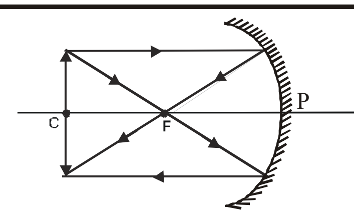
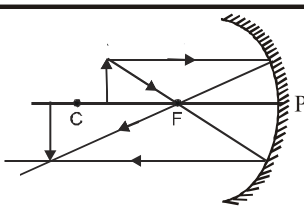
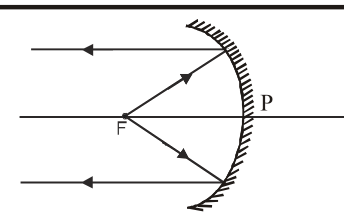
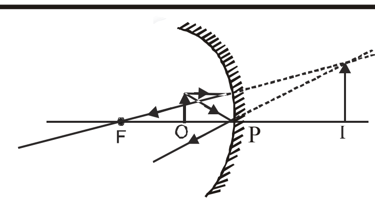


Fig. 1.21 Concave mirror

IMAGE FORMED BY THE CONCAVE MIRROR

Position of object	Position of image	Nature	Ray diagram
At infinity	At the focus	Real, inverted & diminished	
Between infinity & centre of curvature	Between focus & centre of curvature	Real, inverted & small in size	
At centre of curvature	At centre of curvature	Real, inverted and of the same size	
Between focus & centre of curvature	Beyond centre of curvature	Real, inverted and enlarged	
At focus	At infinity	Real, inverted and very large	
Between Focus & Pole	Behind the mirror	Erect, virtual & enlarged	

Uses of Concave Mirror

Makeup and shaving mirrors are concave mirrors. When you place your face between the mirror and its focal point, you see an enlarged virtual image of yourself. Concave mirrors are also used in a new method for displaying the speed of a car, as a dentist mirror, in floodlight etc.

REFLECTION THROUGH CONVEX MIRROR

When a narrow beam of light travelling parallel to the principal axis is incident on the reflecting surface of the mirror, the beam after reflection appear to diverge from a point on the principal axis.

When a ray incident on convex mirror in the direction of centre of curvature after reflection comes back along the same path.
When a ray incident on convex mirror parallel to the principal axis, after reflection, appears to come from the focus.
A ray appearing to pass through the focus is reflected parallel to the principal axis.

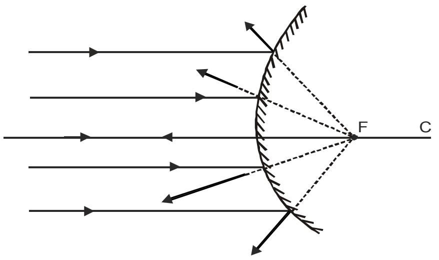


Fig. 1.22 Convex mirror

IMAGE FORMED BY CONVEX MIRROR

A convex mirror forms only virtual images for all positions of the real object. The image is always virtual, erect, smaller than the object and is located between the pole and the focus. The image becomes smaller and moves closer to the focus as the object is moved away from the mirror.

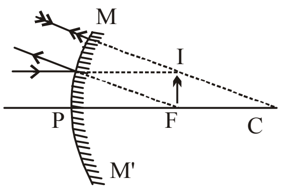


Fig. 1.23 (a)

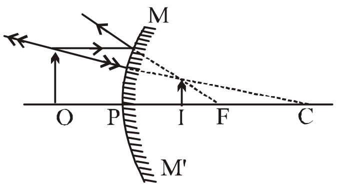


Fig. 1.23 (b)

The virtual image is diminished in size and upright, relative to the object. A convex mirror form a virtual image of the object, no matter where in front of the mirror the object is placed.

Uses of Convex Mirror

Convex mirrors, give a wider field of view than do other types of mirrors. Therefore, they are often used for security purposes, as in figure 1.24.
A mirror with a wide field of view is also needed to give a driver a good rear view. Thus, the outside mirror on the passenger side is often a convex mirror. Printed on such a mirror is usually the warning "vehicles in mirror are closer than they appear."


Fig. 1.24 : Security mirror


Fig. 1.25 : Rear view mirror

The reason for the warning is that the virtual image in figure is reduced in size and therefore looks smaller, just as a distant object would appear in a plane mirror. An unwary driver, thinking that the side-view mirror is a plane mirror, might incorrectly deduce from the small size of the image that the car behind is far enough away to ignore.
Convex mirror also used in street lighting.

COMPARING THE FIELD OF VIEW OF A PLANE MIRROR AND A CONVEX MIRROR

For a fair comparison to be made the two mirrors must be the same size and the eye must be placed at the same distance from each of them. The maximum angle of view is obtained when the angle of reflection at the mirror is a maximum, i.e., when the normal to the mirror are drawn at the extreme edges of the mirror.
The normals to the convex mirror are lines which are continuations of the radii at the edges of the mirror. Once the angles of reflection have been drawn, equal angles must be drawn on the other side of the normals to give the position of the incident rays.
The angle of incidence for the convex mirror is much greater than the angle of incidence for the plane mirror, hence the convex mirror has a greater field of view than that of plane mirror.

SIGN CONVENTION

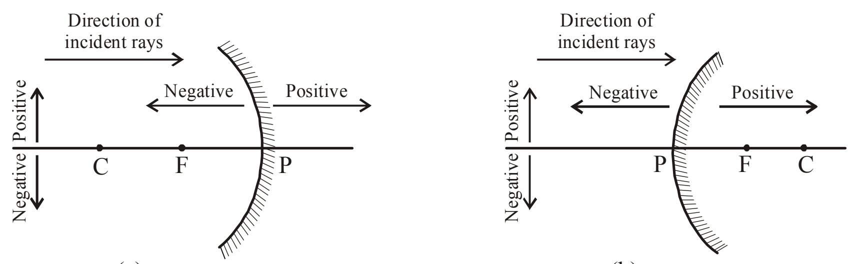
(1) All distances are measured from the pole.

(2) The distance measured along the direction of propagation of light are taken as positive and the direction opposite to the propagation of light is taken as negative.

(3) The distances (heights) measured above the principal axis i.e. along positive Y axis, are taken as positive while distances below the principal axis i.e. along negative Y axis are taken as negative.

In this convention, the focal length (f) and radius of curvature (R) are negative for a concave mirror and positive for a convex mirror.

The sign convention can be summarized in the following figure.



(a) (b)

Fig. 1.26

Note : Many students get confused in applying sign convention and a small error in sign of one variable will throw all your calculation. Please study 3 points carefully (put known quantities with proper sign, unknown quantity will come automatically with proper sign).

In following situations, the sign convention has been applied.

1. Consider the mirror shown in Fig. 1.27 (a). Here, the object is on the left and image is also on the left. The mirror is a concave mirror. The incident ray is directed from left to right and so the positive X-axis is also from left to right.
Here, object distance $u = -PO$, image distance
$v = -PI$ radius of curvature $R = -PC$, focal length $f = -ve$.

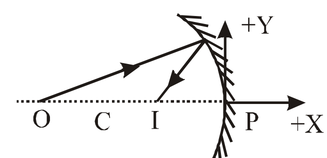


Fig. 1.27 (a)

2. Consider the mirror shown in Fig. 1.27 (b). Here, the object is on the left and image is on the right and the mirror concave. The incident ray is once again from left to right and so the positive X-axis.
Here, object distance $u = -PO$, image distance $v = +PI$,
radius of curvature $R = -PC$, focal length $f = -ve$.

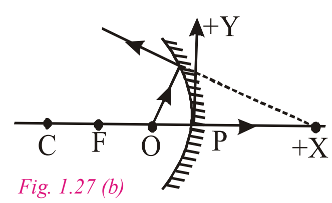


Fig. 1.27 (b)

3. Consider the mirror shown in Fig. 1.27 (c). Here, the object is virtual and on the left, image is also on the right and the mirror is a convex. The incident ray is from the right and the positive X-axis is from right to left.
Here, object distance $u = +PO$, image distance $v = -PI$, radius of curvature $R = +PC$, focal length $f = +ve$.

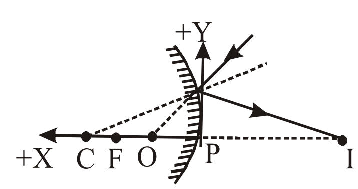


Fig. 1.27 (c)

RELATION BETWEEN FOCAL LENGTH (*F*) AND RADIUS OF CURVATURE (*R*) FOR

The focal length (f) of a mirror is half of the radius of curvature (R), that is, $f = \dfrac{R}{2}$

Proof : In fig. 1.28, incident ray OX is parallel to the principal axis. After reflection, it actually passes through focus F in case of concave mirror and appears to come from focus F in case of a convex mirror. CXN is normal to mirror at X.

For concave mirror (Fig.1.28 (a) (because $\angle i = \angle r$)

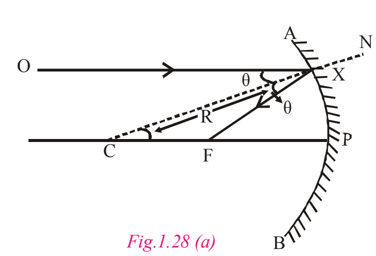


Fig.1.28 (a)

$\angle OXC = \angle FXC = \theta$

But $\angle OXC = \angle XCF$ (alternate angles)

For convex mirror (Fig. 1.28 (b)

$\angle OXN = \angle YXN = \theta$

But $\angle OXN = \angle XCF$ (corresponding angles) and $\angle YXN = \angle FXC$ (vertically opposite)

Hence (in both cases), $\angle FXC = \angle XCF$ there fore, in ΔFCX, $FC = FX$

For mirror of small aperture, X will be near P, then $FX = FP$

Hence, $FC = PF$ and $2\ PF = PF + PF = PF + FC = PC$ i.e. $2f = R$ or $f = R/2$ (Proved).

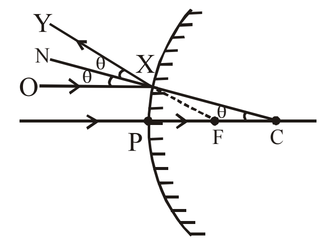


Fig. 1.28 (b)

CHECK *Point*

Her eye at point P looks into the mirror. Which of the numbered cards can she see reflected in the mirror?

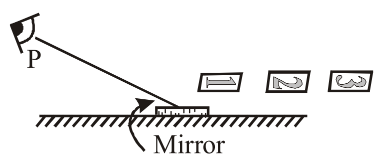


Fig. 1.29

SOLUTION

Card number 2, she can see through the mirror. According to law of reflection, angle of incidence is equal to angle of reflection. Light ray coming from card number 2 makes the same angle with the normal at the point of incidence as the light ray going to eye makes with the normal.

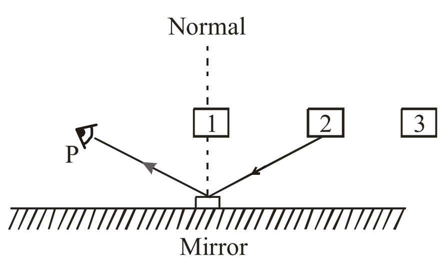


Fig. 1.30

MIRROR FORMULA

A relationship among the object distance (u), the image distance (v) and the focal length (f) of a mirror is called the mirror formula.

The formula is given by $\dfrac{1}{f} = \dfrac{1}{u} + \dfrac{1}{v}$

Proof: Take an object AB beyond C of a concave mirror MM'. A ray AD parallel to principal axis passes through focus after reflection. Another ray AE which is passing through C comes back along the same path after reflection. These two reflected rays intersect at A'. From A' draw perpendicular $A'B'$ on the principal axis. So $A'B'$ is real and inverted image which is formed between C and F which is smaller than the object in size.

Draw DG perpendicular to the principal axis. So, applying sign convention, we get $PB = -u$; $PB' = -v$; $PF = -f$; $PC = -2f$

In ΔABC and $\Delta A'B'C$, $\angle ABC = \angle A'B'C = 90°$

$\angle ACB = \angle A'CB'$ (Vertically opposite angles)

$\therefore \Delta ABC \sim \Delta A'B'C$ (AA similarity)

$\dfrac{AB}{A'B'} = \dfrac{BC}{B'C}$ (Corresponding sides of similar triangles are in proportion) ....(1)

In ΔDGF and $\Delta A'B'F$, $\angle DGF = \angle A'B'F = 90°$

$\angle DFG = \angle A'FB'$ (Vertically opposite angles)

$\Delta DGF \sim \Delta A'B'F$ (AA similarity)

$\dfrac{DG}{A'B'} = \dfrac{GF}{B'F}$ (Corresponding sides of similar triangles are in proportion)

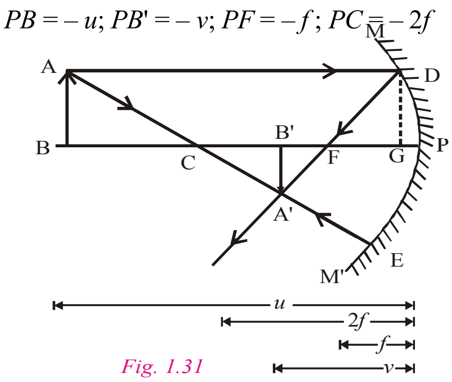


Fig. 1.31

But AB = DG (the perpendicular distance between two parallel lines are equal)

$$\therefore \quad \frac{AB}{A'B'} = \frac{GF}{B'F} \qquad ...(2)$$

From eq. (1) and (2), we get, $\dfrac{BC}{B'C} = \dfrac{GF}{B'F}$ ...(3)

Let us assume that mirror is very small,

$\therefore$ G and P are very close to each other so that GF = PF.

From (3), $\dfrac{BC}{B'C} = \dfrac{PF}{B'F} \Rightarrow \dfrac{PB-PC}{PC-PB'} = \dfrac{PF}{PB'-PF} \Rightarrow \dfrac{-u-(-2f)}{-2f-(-v)} = \dfrac{-f}{-v-(-f)}$

$$\Rightarrow \frac{-u+2f}{-2f+v} = \frac{-f}{-v+f} \Rightarrow (-v+f)(-u+2f) = -f(-2f+v)$$

$$\Rightarrow \quad vu - 2fv - fu + 2f^2 = 2f^2 - fv \Rightarrow uv = -fv + 2fv + fu$$

$\therefore uv = vf + uf$

Dividing both sides by uvf,

$$\frac{uv}{uvf} = \frac{vf}{uvf} + \frac{uf}{uvf} \Rightarrow \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

ILLUSTRATION : 1.5

The radius of curvature of a spherical mirror is 20 cm. What is its focal length ?

SOLUTION :

As we know, focal length (f) of a mirror is half of the radius of curvature (R).

$$\therefore f = \frac{R}{2} = \frac{20}{2} = 10\,\text{cm.}$$

ILLUSTRATION : 1.6

An object is placed at a distance of 10 cm from a convex mirror of focal length 15 cm. Find the position and nature of the image.

SOLUTION :

Given : $u = -10$ cm, $f = +15$ cm, $v = ?$

Using the mirror formula $\dfrac{1}{f} = \dfrac{1}{u} + \dfrac{1}{v}$, we have

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{15} - \frac{1}{(-10)} \quad \text{or} \quad \frac{1}{v} = \frac{1}{15} + \frac{1}{10} = \frac{2+3}{30} = \frac{5}{30} \quad \text{or} \quad v = \frac{30}{5} = 6 \text{ cm.}$$

Hence, the image is formed at a distance of 6 cm behind the mirror. The image is virtual and erect.

ILLUSTRATION : 1.7

We wish to obtain an erect image of an object, using a concave mirror of focal length 15 cm. What should be the range of distance of the object from the mirror ? What is the nature of the image? Is the image larger or smaller than the object? Draw a ray diagram to show the image formation in this case.

SOLUTION :

Here, focal length, $f = -15$ cm.

For getting an erect image using a concave mirror the object should be placed at a distance less than the focal length (i.e.) 15 cm from pole. Image will be virtual, enlarged and erect.

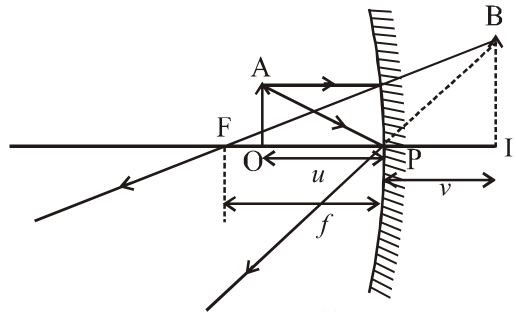


Fig. 1.32

ILLUSTRATION : 1.8

A concave mirror and a convex mirror are placed co-axially, their reflecting surfaces facing each other. Their focal lengths are 15 and 12 cm respectively. An object placed between them is 20 cm from the concave mirror. The image formed by it is at the object itself. Calculate the distance of the concave mirror from the object.

SOLUTION :

In a concave mirror for the image to be formed at the object itself, the latter must be at the centre of curvature. But here, it is at a distance of 20 cm from mirror whose distance is not the radius of curvature. The radius of curvature is twice the focal length or 2×15 or 30 cm. The fact of the matter is the reflected rays from the concave mirror are reflected back along the same path forming the image at the object itself. This can happen only if the reflected rays falling on the mirror are normal to the mirror.

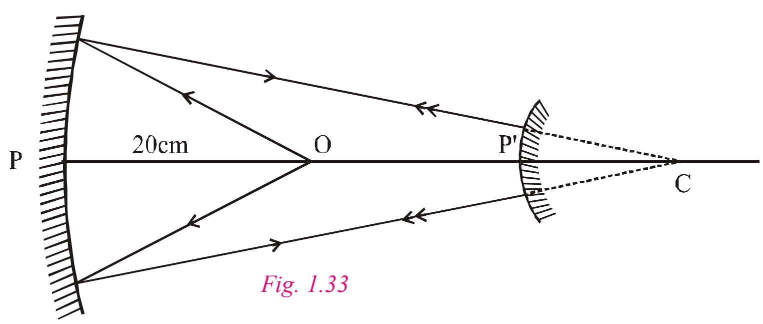


Fig. 1.33

O is object. $OP = 20$ cm, $f = 15$ cm (of concave mirror)

The reflected rays from concave mirror are reflected back by convex mirror.

$\therefore$ C must be centre of curvature of the latter. So its radius of curvature = twice its focal length i.e. 12×2 or 24 cm.

Now, if there were no convex mirror, the concave mirror would form an image of O at C. Then we would have for concave mirror.

$u = +20$ cm, $f = +15$ cm, $v = PC = ?$

Now, $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$ i.e., $\frac{1}{v} + \frac{1}{+20} = \frac{1}{+15}$

$\therefore$ $\frac{1}{v} = \frac{1}{15} - \frac{1}{20} = \frac{1}{60}$ or $v = PC = 60$ cm

But we want OP'

Now $PO' = PC - P'C = 60 - 2 \times 12 = 36$ cm.

($P'C$ = radius of curvature of convex mirror i.e. twice its focal length)

MAGNIFICATION

If the mirror is plane, the size of the image is always equal to the size of the object i.e., **magnification is unity**. But the case is different for a curved mirror. The size of the image is different from the size of the object in such a 'mirror'. Image may be greater or smaller in size than the object depending upon the nature of the mirror or the location of the object.

Let I and O be the size of the image and the object respectively. The ratio $\frac{I}{O}$ is called **magnification**, and it is denoted by m.

Magnification, $m = \frac{I}{O} = -\frac{v}{u}$

This is also called **linear magnification**.
Here u and v represent the distance of the object and the image from the pole of the mirror respectively.
Magnification m can be positive or negative. If m is positive, it means that I and O are both on the same side of the principal axis. That is, image is erect. Similarly, if m is negative, it means that I and O are on opposite sides of the principal axis. That is image is inverted.

Superficial magnification: It is the ratio of area of image to the area of object. superficial magnification $= \frac{\text{area of image}}{\text{area of object}} = \frac{v^2}{u^2}$

Other formulae of magnification

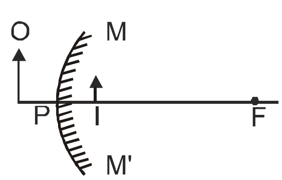
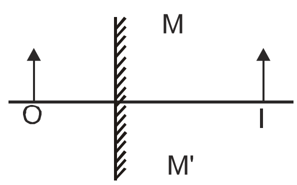
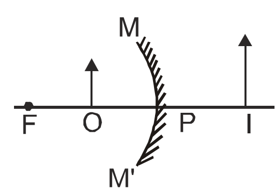
$$\text{Magnification, } m = -\frac{v}{u} = -\left(\frac{v-f}{f}\right) = \frac{f-v}{f} = -\left(\frac{f}{u-f}\right) = \frac{f}{f-u}$$

NEWTON'S FORMULA

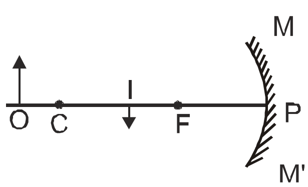
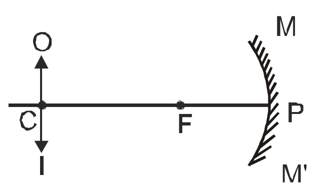
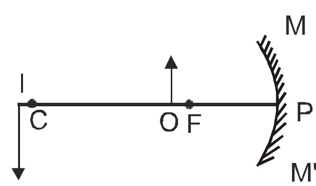
This formula provides a relationship among the focal length (f), the distance of the object from focus (x) and the distance of the object from focus (y).
This can be expressed as $xy = f^2$
Note that here the object distance and the image distance are measured from the focus of the mirror not from the pole.

IDENTIFICATION OF MIRROR BY THE SIZE AND NATURE OF THE IMAGE

(i) If object and image are of same nature (i.e. both on the same side of the mirror) then they will be inverted.
(ii) If the object and image are on the opposite sides of the mirror then image is erect relative to object.
For real extended object if the image formed by a single mirror is erect it is always virtual (i.e. m is $+ve$) and in this situation if the size of image is

Smaller than object, the mirror is convex	Equal to object, the mirror is plane	Larger than object, the mirror is concave
 m < +1	 m = +1	 m > +1

So, by observing the size of erect image in a mirror we can decide the nature of the mirror i.e. whether it is convex, concave or plane. For real extended object if the image formed by a single mirror is inverted it is always real (i.e., m is $-ve$) and the mirror is concave. In this situation if the size of image is

Smaller than object, object is between the ∞ and C and image is between F and C	Equal to object, object is at C and image is at C	Larger than object, object is between C and F and image is between C & ∞
 m < – 1	 m = – 1	 m > – 1

Knowledge ENHANCER

Every part of a mirror forms complete image, if a part of mirror (say half) is obstructed (say covered with black paper) full image will be formed but intensity will be reduced.

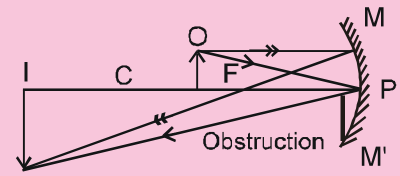


Fig. 1.34

ILLUSTRATION : 1.9

An object, 4.0 cm in size, is placed at 25.0 cm in front of a concave mirror of focal length 15.0 cm. At what distance from the mirror should a screen be placed in order to obtain a sharp image? Find the nature and the size of the image.

SOLUTION :

Object-size, $h = +4.0$ cm; Object-distance, $u = -25.0$ cm; Focal length, $f = -15.0$ cm;
Image-distance, $v = ?$ Image-size, $h' = ?$

From $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$ or $\frac{1}{v}=\frac{1}{f}-\frac{1}{u}=\frac{1}{-15.0}-\frac{1}{-25.0}=-\frac{1}{15.0}+\frac{1}{25.0}$

or $\frac{1}{v}=\frac{-5.0+3.0}{75.0}=\frac{-2.0}{75.0}$ or $v = -37.5$ cm.

The screen should be placed at 37.5 cm. from the mirror. The image is real.

Also, magnification, $m=\frac{h'}{h}=-\frac{v}{u}$ or $h'=-\frac{vh}{u}=\frac{(-37.5\text{cm})\,(+4.0\text{cm})}{(-25.0\text{cm})}$

Height of the image, $h' = -6.0$ cm.
The image is inverted and enlarged.

ILLUSTRATION : 1.10

A convex mirror used for rear-view on an automobile has a radius of curvature of 3.00 *m*. If a bus is located at 5.00 *m* from this mirror, find the position, nature and size of the image.

SOLUTION :

Radius of curvature, $R = +3.00\ m$; Object-distance, $u = -5.00\ m$; Image-distance, $v = ?$ Height of the image, $h' = ?$

Focal length, $f = R/2 = +\frac{3.00\text{m}}{2} = +1.50$ m

Since $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$ or $\frac{1}{v}=\frac{1}{f}-\frac{1}{u}=+\frac{1}{1.50}-\frac{1}{(-5.00)}=\frac{1}{1.50}+\frac{1}{5.00}=\frac{5.00+1.50}{7.50}$

$\Rightarrow$ $v=\frac{+7.50}{6.50}=+1.15m$

The image is 1.15*m* at the back of the mirror.

Magnification, $m=\frac{h'}{h}=-\frac{v}{u}=-\frac{1.15m}{-5.00m}=+0.23$

The image is virtual, erect and smaller in size by a factor of 0.23.

ILLUSTRATION : 1.11

A concave makeup mirror is that designed so that the virtual image is twice the size of the object, when the distance between the object and mirror is 15 cm. Determine the radius of curvature of the mirror.

SOLUTION :

As we know, magnification $m=-\frac{v}{u}=+2$ where u is 15 cm. Therefore, $v = -2u = -30$ cm.

Therefore, the focal length is found from $\frac{1}{f}=\frac{1}{u}+\frac{1}{v}$ which yields $f = +30$ cm. Therefore, $R = 2f = 60$ cm.

ILLUSTRATION : 1.12

The image of an object viewed in a concave mirror of focal length 25.0 cm appears 75.0 cm in front of the mirror. Find the location of the object and the magnification.

SOLUTION :

We have, $\frac{1}{u}=\frac{1}{f}-\frac{1}{v}=\frac{1}{25.0}-\frac{1}{75.0}=0.0267\text{ cm}^{-1} \Rightarrow$ object distance, $u = 37.5$ cm

Magnification $m=-\frac{v}{u}=\frac{-(75.0\text{ cm})}{37.5\text{ cm}}=-2.00$

ILLUSTRATION : 1.13

A concave mirror of focal length *f* produces a real image n times the size of the object. What is the distance of the object from the mirror?

SOLUTION :

Here, magnification, $m = -n$; $m=\frac{f}{f-u}$

$$-n=\frac{-f}{-f-u} \Rightarrow nf+nu=-f$$

$$nu=-f-nf \Rightarrow u=\frac{-(n+1)}{n}f$$

ILLUSTRATION : 1.14

The focal length of a concave mirror is 30 cm. Find the position of the object in front of the mirror, so that the image is three times the size of the object.

SOLUTION :

Here image can be real or virtual. If the image is real

$f = -30$ cm, $u = ?$, $m = -3$

$$m=\frac{f}{f-u} \Rightarrow 3=\frac{-30}{-30-u} \Rightarrow u=-40\text{ cm.}$$

If the image is virtual $m=\frac{f}{f-u} \Rightarrow 3=\frac{-30}{-30-u} \Rightarrow u=-20$ cm.

REFRACTION OF LIGHT

The bending of the light ray from its path in passing from one medium to the other medium is called refraction of light.

If the refracted ray bends towards the normal relative to the incident ray (Passing obliquely), then the second medium is said to be denser than the first medium. But if the refracted ray bends away from the normal, then the second medium is said to be rarer than the first medium.

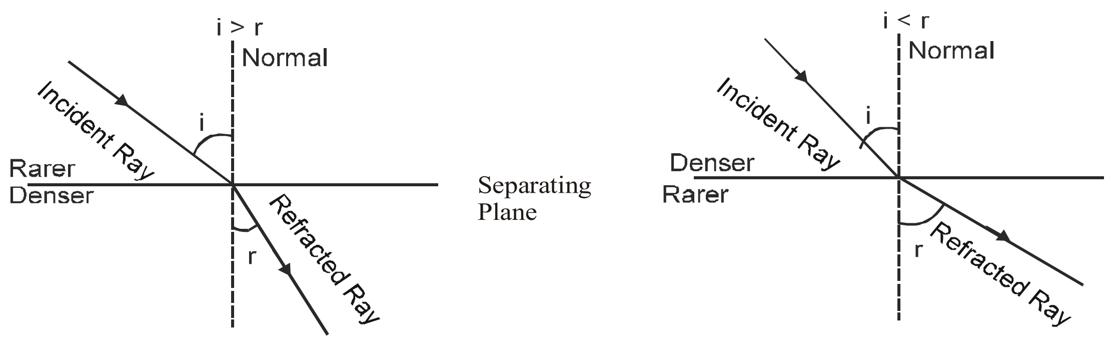


Fig. 1.35 (a) *Fig. 1.35 (b)*

If a ray of light passing normally i.e., at right angles from one medium to another optical medium then it does not bend or deviate from its path.

Cause of refraction of light: Refraction of light takes place due to change in the speed of light as it enters from one medium to another medium.

Refraction causes many illusions. One of them is the **apparent bending of a stick that is partially submerged in water**. The submerged part appears closer to the surface than it actually is. The same is true when you look at a fish in water. The fish appears nearer to the surface and closer than it really is (Fig. 1.36). If we look straight down into water, an object submerged 4 meters beneath the surface appears to be only 3 meters deep. Because of refraction, submerged objects appear to be magnified.

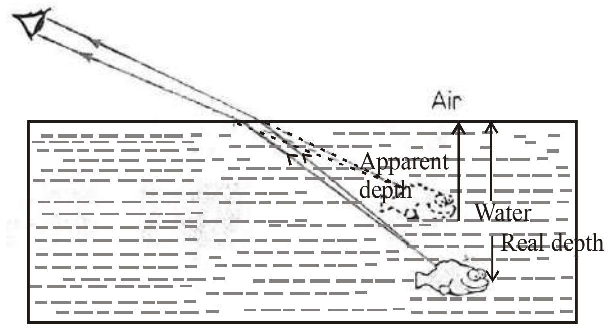


Fig.1.36 Because of refraction, a submerged object appears to be nearer to the surface than it actually is

Atmospheric Refraction

Refraction occurs in the earth's atmosphere. Whenever we watch a sunset, we see the sun for several minutes after it has sunk below the horizon (Fig. 1.36). The earth's atmosphere is thin at the top and dense at the bottom. Because light travels faster in thin air than in dense air, parts of the wavefronts of sunlight at high altitude travel faster than parts closer to the ground. Light rays bend. The density of the atmosphere changes gradually, so light rays bend gradually and follow a curved path. So we gain additional minutes of daylight each day. Furthermore, when the sun (or moon) is near the horizon, the rays from the lower edge are bent more than the rays from the upper edge. This shortens the vertical diameter, causing the sun to appear elliptical figure).

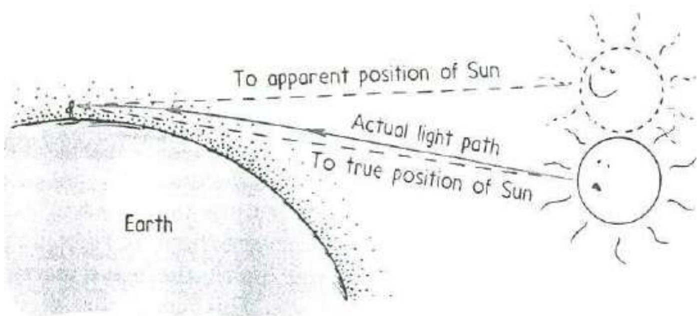


Fig. 1.37. Because of atmospheric refraction, when the sun is near the horizon it appears to be higher in the sky.

CHECK Point

If, while standing on the bank of a stream, you wished to spear a fish swimming in the water out in front of you, would you aim above, below, or directly at the observed fish to make a direct hit? If you decided instead to zap the fish with a laser, would you aim above, below, or directly at the observed fish? Defend your answer.

SOLUTION

When you try to hit the fish with a spear, you need to aim below as the fish is actually at a lower depth than that observed by you from outside the water due to refraction of light.
When you aim with a laser light then also you should aim much below as the path of laser will change as it enters in water. Since it is going from rarer to denser medium, it bends towards the normal and deviates from the original path.

Laws of Refraction

There is two laws of refraction

1. The incident ray, the refracted ray, and the normal to the refracting surface at the point of incidence are in the same plane.
2. The ratio of *sine* of angle of incidence to the *sine* of angle of refraction is constant for a pair of media i.e. $\frac{\sin i}{\sin r} = \text{constant } ({}_1u_2)$

   Where ${}_1\mu_2$ is the refractive index of medium 2 w.r.t. medium 1. This law is also known as **snell's law.**

Application of Snell's Law

When light passes from rarer to denser medium it bends toward the normal fig 1.38 (a).
Using Snell's law

$\mu_1 \sin\theta_1 = \mu_2 \sin\theta_2 \quad \Rightarrow \frac{\sin\theta_1}{\sin\theta_2} = \frac{\mu_2}{\mu_1}$

Thus, if $\mu_2 > \mu_1$ then $\theta_2 < \theta_1$
When light passes from denser to rarer medium it bends away from the normal fig 1.38(b).

From Snell's law, $\frac{\sin\theta_1}{\sin\theta_2} = \frac{\mu_2}{\mu_1}$

Thus, if $\mu_2 < \mu_1$ then $\theta_2 > \theta_1$

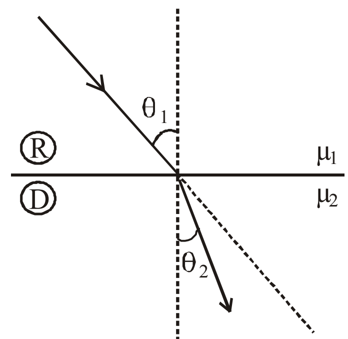


Fig. 1.38 (a) Ray bending towards normal.

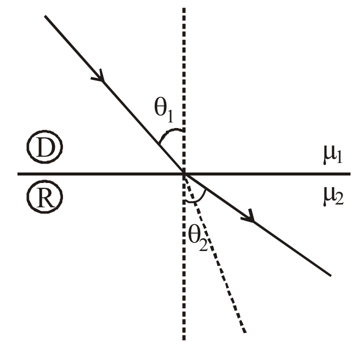


Fig. 1.38 (b) Ray bending away from normal.

When light propagates through a series of layers of different medium, then according to Snell's law

$\mu_1 \sin\phi_1 = \mu_2 \sin\phi_2 = \mu_3 \sin\phi_3 = ... = \text{constant}$

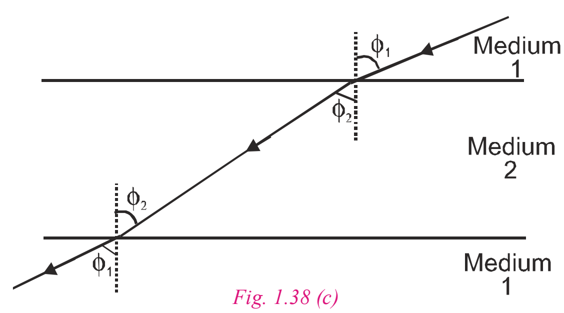


Fig. 1.38 (c)

If $_1\mu_2$, $_2\mu_3$ and $_3\mu_1$ be refractive index of medium 2 w.r.t. medium 1, refractive index of medium 3 w.r.t medium 2 and refractive index of 1 w.r.t. 3 respectively then $_1\mu_2 \times {_2\mu_3} \times {_3\mu_1} = 1$.

REFRACTIVE INDEX

Light travels through a vacuum at a speed $c = 3.00 \times 10^8$ m/s. It can also travel through many materials, such as air, water and glass. Atoms in the material absorb, reemit and scatter the light, however. Therefore, light travels through the material at a speed that is less than c, the actual speed depending on the nature of the material.
To describe the extent to which the speed of light in a material medium differs from that in a vacuum, we use a parameter called the index of refraction (or refractive index).

Absolute Refractive Index

It is defined as *the ratio of speed of light in free space c to that in a given medium v.*

i.e. μ or $n = \frac{c}{v}$ ... (1)

Also, μ or $n = \dfrac{\sin i}{\sin r}$ (incident ray in vacuum or air)

It is a scalar and has no units and dimensions.
As in vacuum or free space, speed of light of all wavelengths is maximum and equal to c, so, for all wavelengths the refractive index of free space is minimum and is $\mu = \dfrac{c}{v} = \dfrac{c}{c} = 1$

For a given light, denser is the medium, lesser will be the speed of light and so greater will be the refractive index, e.g. as $v_{\text{glass}} < v_{\text{water}}$, $\mu_G > \mu_w$

i.e. for a given light refractive index depends on nature of medium [i.e., $\mu \propto (1/v)$]s

For a given medium (other than free-space), the speed of light of different wavelengths is different,i.e., $v \propto \lambda$ and $\mu = (c/v)$, $\mu \propto (\lambda)$ i.e. greater the wavelength of light lesser will be the refractive index e.g. $\lambda_R > \lambda_B$, so in water or glass $\mu_R < \mu_B$, i.e., for a given medium (other than free space) refractive index depends on wavelength of light.

As for light in free space $c = f\,\lambda_0$ and in a medium $v = f\,\lambda$,

$$\mu = \frac{c}{v} = \frac{\lambda_0}{\lambda} \qquad \text{... (2)}$$

i.e., for a given light and medium refractive index is equal to the ratio of wavelength of light in free space to that in the medium.
Refractive index decreases with the increase in temperature.

Relative Refractive Index

When light passes from one medium to the other, the refractive index of medium 2 relative to 1 is written as ${}_1\mu_2$ and is defined as

$$ {}_1\mu_2 = \frac{\mu_2}{\mu_1} = \frac{(c/v_2)}{(c/v_1)} = \frac{v_1}{v_2} \qquad \text{... (3)}$$

While using the concept of relative μ, it must be kept in mind that :

$$ {}_2\mu_1 = \frac{\mu_1}{\mu_2} = \frac{v_2}{v_1} \qquad \text{So that, } ({}_1\mu_2)({}_2\mu_1) = \frac{v_1}{v_2} \times \frac{v_2}{v_1} = 1 \qquad \text{i.e., } {}_1\mu_2 = \frac{1}{{}_2\mu_1} \qquad \text{.... (4)}$$

Usually 'μ' is used for relative refractive index and it implies the refractive index of denser medium relative to rarer one,

i.e., $\mu = \dfrac{\mu_D}{\mu_R} = \dfrac{v_R}{v_D} > 1$

In lens theory μ is used for the refractive index of material of lens relative to the medium,

i.e., $\mu = \dfrac{(\mu)_{\text{Lens}}}{(\mu)_{\text{Medium}}}$ and can be greater than, less than or equal to unity.

CHECK Point

If you place a glass test tube in water, you will be able to see the tube. If you place it in clear soyabean oil, you may not be able to see it. What does this tell you about the speed of light in the oil and in the glass?

SOLUTION

If a glass test tube is placed in water and it can be seen, this indicates the speed of light in glass and water is different. So refraction takes place.
When the same glass tube is placed in soyabean oil, it cannot be seen that means the speed of light is same in both oil and glass. So no refraction takes place between the two media.

Knowledge ENHANCER

Conditions of no refraction : If light is incident normally on a boundary i.e., $\angle i = 0°$

Then from Snell's law

$\mu_1 \sin 0 = \mu_2 \sin r \Rightarrow \sin r = 0$ i.e. $\angle r = 0$

i.e., light passes undeviated from the boundary. (so boundary will be invisible)

If the refractive indices of two media are equal i.e., if,

$\mu_1 = \mu_2 = \mu$

Then from Snell's law

$\mu_1 \sin i = \mu \sin r \Rightarrow \angle i = \angle r$

i.e., ray passes undeviated from the boundary with $\angle i = \angle r \neq 0$ and boundary will not be visible.

This is also why a transparent solid is invisible in a liquid if $\mu_s = \mu_L$

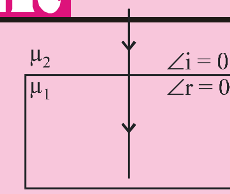


Fig. 1.39 (a)

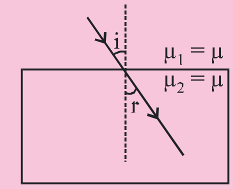


Fig. 1.39 (b)

REFRACTION THROUGH A RECTANGULAR GLASS SLAB

Let us consider a glass slab of thickness t and refractive index μ on which a ray AB is incident at B. BC and CD are the refracted ray and emergent ray respectively. x is the displacement in the emergent ray due to refraction.

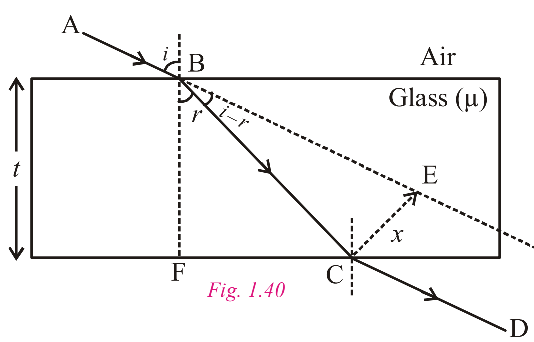


Fig. 1.40

From ΔBCE,

$$\sin(i - r) = \frac{CE}{BC}$$

or $$\sin(i - r) = \frac{x}{BC} \qquad \text{..... (1)}$$

Also, from ΔBFC,

$$\cos r = \frac{BF}{BC} = \frac{t}{BC} \qquad \text{..... (2)}$$

Equating BC from (1) and (2), we get

$$\frac{x}{\sin(i - r)} = \frac{t}{\cos r} \Rightarrow x = \frac{t \sin(i - r)}{\cos r}$$

$x = t \sec r . \sin(i - r)$ x is called the lateral displacement

Lateral displacement depends on the following factors.

(i) Refractive index of the medium (μ) $x \propto \mu$

(ii) Thickness of the medium (t) $x \propto t$

(iii) Angle of incidence (i) $x \propto i$

(iv) Wavelength of light (λ) $x \propto \frac{1}{\lambda}$

ILLUSTRATION : 1.15

Light waves of 5895 Å wavelength travels from vacuum to a medium of refractive index of 1.5. Find the velocity of light and wavelength in medium.

SOLUTION :

If velocity of light in vacuum is c then velocity of light in medium is $v = \frac{c}{n} = \frac{3 \times 10^8}{15} = 2 \times 10^8$ m/sec

Wavelength of light in medium $\lambda_m = \frac{\lambda}{n} = \frac{5895}{1.5} = 3930 \text{ A}^\circ$.

ILLUSTRATION : 1.16

The refractive index of water is 4/3 and of glass is 3/2. Calculate the refractive index of glass with respect to water.

SOLUTION :

Let the 3 media be 1, 2 and 3, 1 for air, 2 for water, 3 for glass in that order.

Given : ${}_1\mu_2 = \frac{4}{3}$, ${}_2\mu_3 = ?$, ${}_3\mu_1 = \frac{1}{3/2}$ $\quad [\because {}_1\mu_3 = \frac{3}{2}$ and $\therefore$ ${}_3\mu_1$ is the reciprocal of ${}_1\mu_3]$

Now using the formula, ${}_1\mu_2 . {}_2\mu_3 . {}_3\mu_1 = 1$ and substituting values, we have

$$\frac{4}{3} . {}_2\mu_3 . \frac{2}{3} = 1 \Rightarrow {}_2\mu_3 = \frac{1\times3\times3}{4\times2} = \frac{9}{8}$$

$\therefore$ The refractive index of glass with respect to water is 9/8

ILLUSTRATION : 1.17

The refractive index of a material is 1.33. If velocity of light in vacuum is 3×10^8 ms^{-1}, find the velocity of light in the material.

SOLUTION :

$$\text{Refractivge index, } \mu = \frac{\text{Velocity of light in vacuum}}{\text{Velocity of light in material}}$$

$$\therefore \quad 1.33 = \frac{3\times10^8 \text{ms}^{-1}}{\text{Velocity of light in material}}$$

$$\therefore \quad \text{Velocity of light in material} = \frac{3\times10^8}{1.33} = 2.25\times10^8 \text{ ms}^{-1}$$

LLUSTRATION : 1.18

The angle of incidence in air for a ray of light is 40°. If ray travels through water of refractive index 4/3, find angle of refraction.

SOLUTION :

$$\text{According to snell's law, } {}^a\mu_w = \frac{\sin i}{\sin r}$$

$$\therefore \quad \sin r = \frac{\sin i}{{}^a\mu_w} = \frac{\sin 40}{4/3} = \frac{3\times0.6427}{4} = 0.4820$$

$r = \sin^{-1}(0.4820) = 28.82°$ (approx.)

ILLUSTRATION : 1.19

Light reflected from a fish strikes the surface of the water at an angle of 38° to the normal. What is the angle of refraction of the light into the air ?

SOLUTION :

Snell's law gives, $n_w \sin\theta_1 = n_a \sin\theta_2 \Rightarrow \sin\theta_2 = (1.33)\sin 38°$

Therefore, the angle of refraction of the light into air $\theta_2 = 55°$

ILLUSTRATION : 1.20

Light strikes an interface between two materials of refractive indices n_1 and n_2, at an angle θ_1 to the normal to the surface. Show that a ray of light is bent towards the normal if $n_1 < n_2$ and that a ray is bent away from the normal if $n_1 > n_2$.

SOLUTION :

Snell's law gives for any light ray $\sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1$

If $n_1 < n_2$ then $\sin\theta_2 < \sin\theta_1$ and $\theta_2 < \theta_1$. This means that the ray is bent toward the normal.
If $n_1 > n_2$ then $\sin\theta_2 > \sin\theta_1$ and $\theta_2 > \theta_1$. This means that the ray is bent away from the normal.

ILLUSTRATION : 1.21

One light wave is incident upon a plate of refractive index μ. Find the incident angle i, for which refractive and reflective waves are mutually perpendicular.

SOLUTION :

According to snell's laws, $\dfrac{\sin i}{\sin r} = \mu$

Angle between refractive and reflective waves = $180^\circ - (i + r) = 90^\circ \Rightarrow i + r = 90^\circ \Rightarrow r = 90^\circ - i$

$$\therefore \ \mu = \frac{\sin i}{\sin(90^\circ - i)} = \frac{\sin i}{\cos i} = \tan i \qquad \Rightarrow i = \tan^{-1}(\mu)$$

ILLUSTRATION : 1.22

Figure 1.40, shows the path of ray of light passing through a glass slab. By geometrical construction calculate the refractive index of glass applying Snell's law.

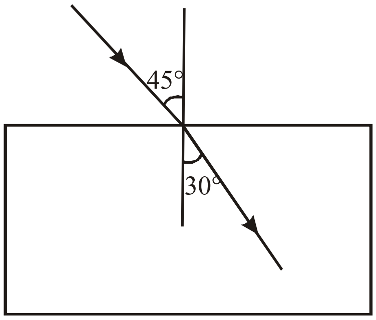


Fig. 1.41

SOLUTION :

AO is the incident ray on the surface of glass and OB is the refracted ray through the glass. With O as centre draw a circle of some suitable radius cutting the incident ray at A and the radius ray at B. Draw perpen diculars AC and BD to the normal COD.

Refractive index $\mu = \dfrac{\sin i}{\sin r} = \dfrac{AC}{BD} = \dfrac{1.2 \text{ cm}}{0.8 \text{ cm}} = 1.5$

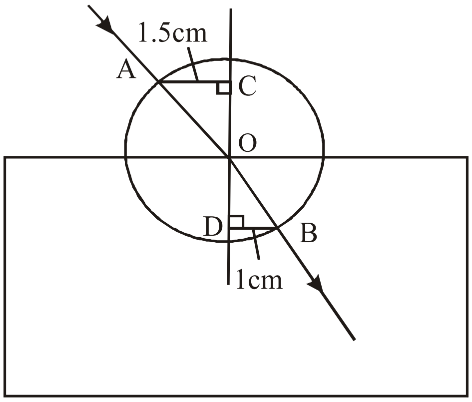


Fig. 1.42

CONNECTING TOPIC

REAL AND APPARENT DEPTHS

When an object is seen from other medium, we don't see its actual depth or height. The depth we see is called apparent depth and the actual depth is called the real depth.

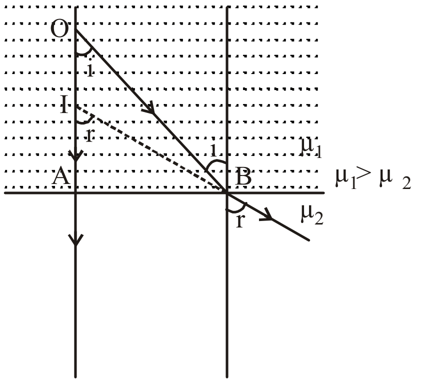


Fig.1.43 (a)

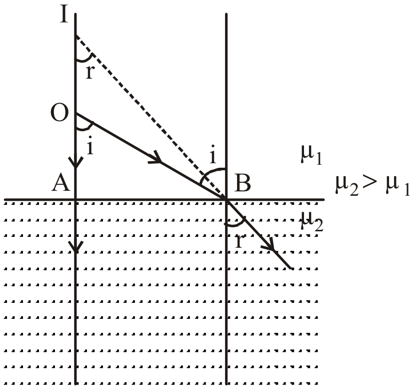


Fig. 1.43(b)

Let us consider an object O placed in a medium of refractive index μ_1. It is being observed by an observer in other medium of refractive index μ_2.

Two rays OA and OP are made incident on the interface separating the two media where they get refracted. OA passes through second medium undeviated as it falls normally. When the refracted rays are produced backward, they meet at I producing virtual image of O there. If $\mu_1 > \mu_2$ [Fig. 1.43 (a)], i.e., observer is in rarer medium, the image is formed at a distance less than the object from the observer. In other words, the image shifts towards the observer.

If $\mu_1 < \mu_2$ [Fig. 1.43 (b)], i.e., observer is in denser medium, the image is formed at a distance greater than the distance of the object from the observer. That is, the image shifts away from the observer.

Let us now calculate the shift OI (= Δt).

If i and r are small,

$$\sin i \approx \tan i = \frac{AB}{OA} \quad \text{and} \quad \sin r \approx \tan r = \frac{AB}{IA}$$

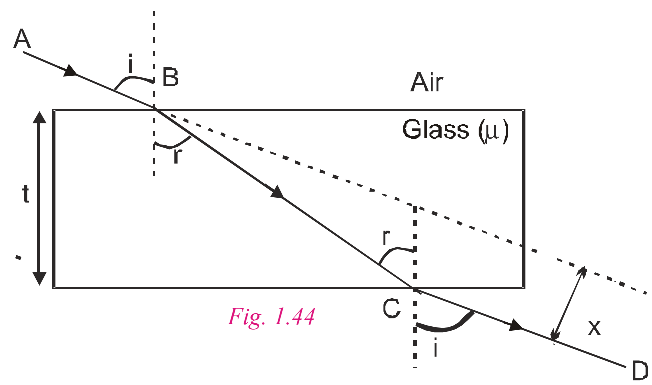


Fig. 1.44

By Snell's law,

$$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1} \Rightarrow \frac{AB}{OA} \times \frac{IA}{AB} = \frac{\mu_2}{\mu_1} \Rightarrow \frac{IA}{OA} = \frac{\mu_2}{\mu_1}$$

Clearly, IA = Apparent depth of object

OA = Real depth of object

$$\therefore \frac{\text{Apparent Depth}}{\text{Real Depth}} = \frac{\mu_2}{\mu_1}$$

Case I : If $\mu_1 = \mu$ and $\mu_2 = 1$ (for air), then

$$\frac{\text{AI}}{\text{AO}} = \frac{\text{Apparent Depth}}{\text{Real Depth}} = \frac{1}{\mu} \quad \text{..... (1)}$$

$$\Rightarrow \quad \mu = \frac{\text{Real Depth}}{\text{Apparent Depth}}$$

Now, shift in image $(\Delta t) = OI$

$$= AO - AI = \left(\frac{AO - AI}{AO}\right)AO = \left(1 - \frac{AI}{AO}\right)AO$$

or $$\Delta t = \left(1 - \frac{1}{\mu}\right)t, \quad \text{From eq. (1)}$$

where $t = AO$ = thickness of the medium in which object is placed.

NOTE : If the object is placed in a medium which consists of a number of media of refractive indices μ_1, μ_2, μ_3, ... and thickness t_1, t_2, t_3, ... respectively, then

$$\text{Virtual depth (AI)} = \frac{t_1}{\mu_1} + \frac{t_2}{\mu_2} + \frac{t_3}{\mu_3} + \ldots\ldots\ldots\ldots$$

$$\text{Virtual displacement (OI)} = t_1\left(1 - \frac{1}{\mu_1}\right) + t_2\left(1 - \frac{1}{\mu_2}\right) + t_3\left(1 - \frac{1}{\mu_3}\right) + \ldots\ldots\ldots\ldots$$

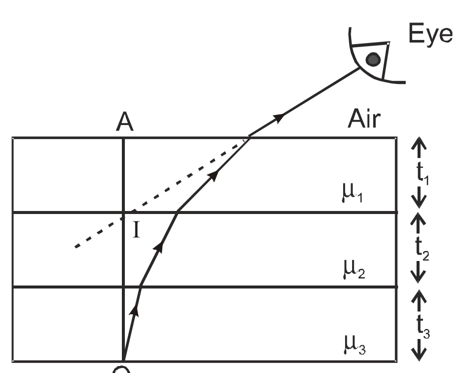


Fig. 1.45

Case II : If $\mu_1 = 1$ (for air) and $\mu_2 = \mu$, then

$$\frac{AI}{AO} = \frac{\text{Apparent Depth}}{\text{Real Depth}} = \mu \quad \text{..... (2)}$$

$\therefore$ Shift in image $= OI = AI - AO$

$$= \left(\frac{AI - AO}{AO}\right)AO = \left(\frac{AI}{AO} - 1\right)AO$$

$$\Rightarrow \quad \Delta t = (\mu - 1)t$$

Case III : When object and observer both are in rarer medium.
Let observer is in air & object is at a point O in air, as shown in figure.
A glass is there in between observer & object. Image forms at point I.
Refractive index of glass is μ.

Virtual displacement $= OI = \left(t - \frac{1}{\mu}\right)$

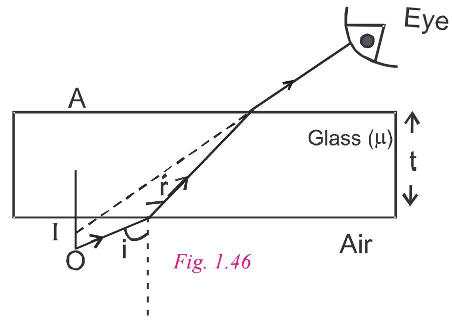


Fig. 1.46

ILLUSTRATION : 1.23

When a glass slab is placed on a dot on a paper, it appears displaced by 4 cm, viewed normally. What is the thickness of slab if the refractive index is 1.5.

SOLUTION :

We know that Displacement $= t\left(1 - \frac{1}{\mu}\right)$ So $4 = t\left(1 - \frac{1}{\mu}\right)$

$$t = \frac{\mu \times 4}{\mu - 1} = \frac{1.5 \times 4}{1.5 - 1} = 12 \text{ cm}$$

TOTAL INTERNAL REFLECTION

When a light ray, travelling from a denser medium to a rarer medium is incident at the interface at an angle of incidence greater than critical angle (c) i.e., the angle of incidence in a denser medium for which the angle of refraction in rarer medium becomes 90º, then light rays reflected back into the denser medium. This phenomenon is called total internal reflection (TIR). Sparkling of diamond, optical fibres etc. are the applications of total internal reflection.
Critical angle: The angle of incidence in a denser medium for which the angle of refraction in rarer medium becomes 90º is called critical angle.

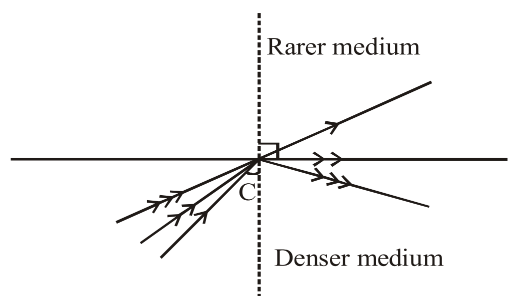


Fig. 1.47

Refractive index of denser medium $\mu = \frac{1}{\sin c}$

LENS

A lens is a piece of transparent material with two refracting surfaces such that at least one is curved and refractive index of used material is different from that of the surroundings.
Convex lens: A thin spherical lens with refractive index greater than that of surrounding behaves as a convergent or convex lens i.e. converges parallel rays. Its central (i.e. paraxial) portion is thicker than marginal one.
Convex lens: If the central portion of a lens (with $\mu_L > \mu_M$) is thinner than marginal, it diverges parallel rays and behaves as a divergent or a concave lens.

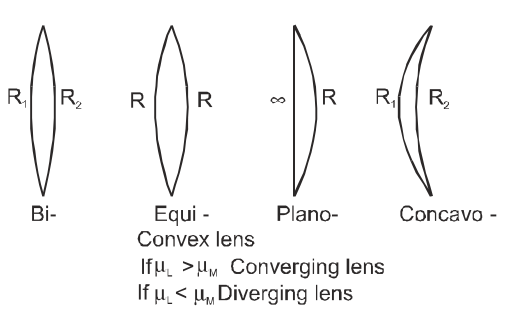


Fig. 1.48 (a)

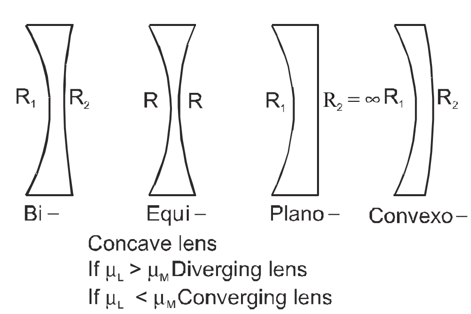


Fig. 1.48 (b)

TERMS RELATED TO THIN SPHERICAL LENS

Optical centre (O) - It is a point for a given lens through which any ray passes undeviated.
Principal axis (C_1C_2) - It is a line passing through optical centre and perpendicular to the lens. The centre of curvature of curved surface always lie on the principal axis (as in a sphere is always perpendicular to surface)

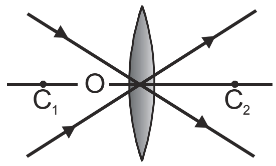


Fig. 1.49 (a)

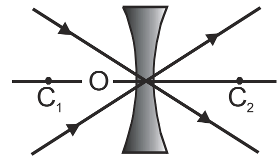


Fig. 1.49 (b)

Principal focus - A lens has two surfaces and hence two focal points first focal point is an object on the principal axis for which image is at infinity while second focal point is an image point on the principal axis for which object is at infinity.

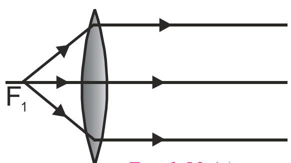


Fig. 1.50 (a)

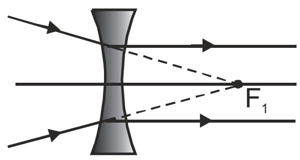


Fig. 1.50 (b)

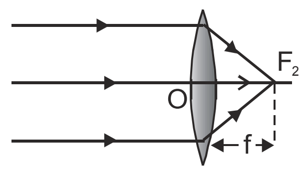


Fig. 1.50 (c)

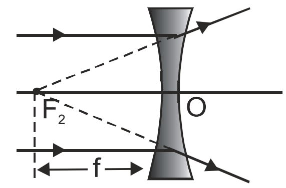


Fig. 1.50 (d)

Focal length (f) - It is defined as the distance between optical centre of a lens and the point where the parallel beam of light converges or appear to converge i.e., focus.
Aperture - In reference to lens, aperture means to effective diameter of its light transmitting area so that brightness i.e. intensity of image formed by a lens which depends on the light passing through the lens will depend on the square of aperture.
i.e. $I \propto (\text{aperture})^2$

SIGN - CONVENTION

1. Whenever and where possible, rays of light are taken to travel from left to right.
2. Transverse distances are measured from optical centre and are taken to be positive while those below it negative.
3. Longitudinal distances are measured from optical centre and are taken to be positive if in the direction of light propagation and negative if opposite to it e.g., according to our convention the sign of R_1, R_2 and f are given.

$R_1(= OC_1)$ = Positive
$R_2(= OC_2)$ = Negative
f (= OF) = Positive

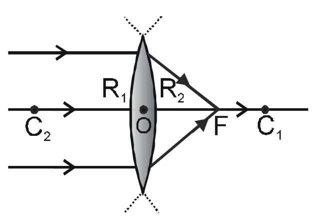


Fig. 1.51 (a)

$R_1(= OC_1)$ = Negative
$R_2(= OC_2)$ = Positive
f (= OF) = Negative

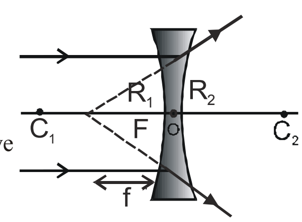


Fig. 1.51 (b)

While using the sign convention it must be kept in mind that
(i) to calculate an unknown quantity the known quantities are substituted with sign in a given formula.
(ii) in the result, sign must be interpreted as there are number of sign conventions and same sign has different meaning in different conventions.

RULES FOR IMAGE FORMATION

In order to locate the image formed by a lens graphically following rules are adopted.

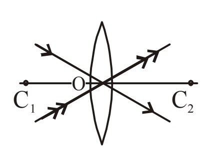


Fig. 1.52 (a)

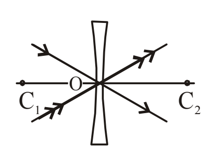
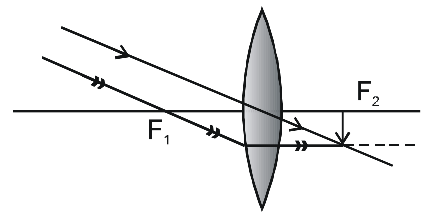
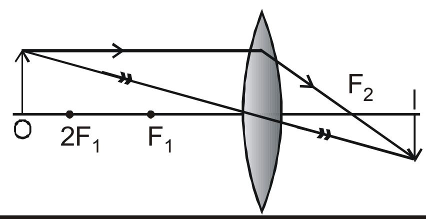
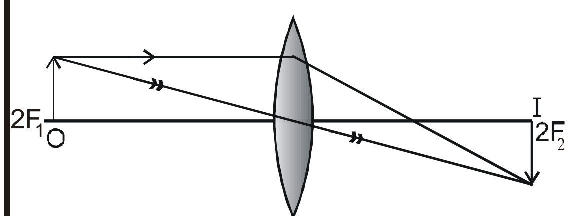
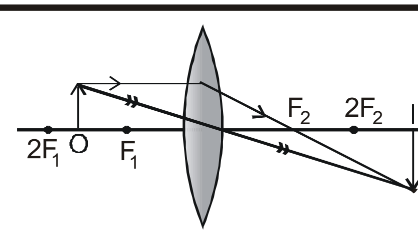
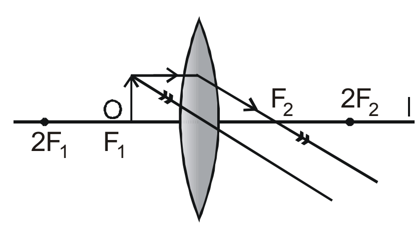
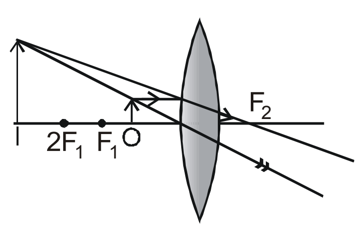


Fig. 1.52 (b)

1. A ray passing through optical centre proceeds undeviated through the lens (by definition of optical centre).
2. A ray passing through first focus or directed towards it, after refraction from the lens becomes parallel to the principal axis (by definition of F_1).
3. A ray passing parallel to the principal axis after refraction through the lens passes or appear to pass through F_2 (by definition of F_2).
4. Only two rays from the same point of an object are needed for image formation and the point where the rays after refraction through the lens intersect or appear to intersect is the image of the object. If they actually intersect each other the image is *real* and if they appear to intersect the image is said to be *virtual*.

IMAGE FORMATION BY A LENS

(a) For Convergent or Convex Lens

Position of object	Details of image	Ray diagram
At infinity	Real, inverted, diminished ($m << -1$), at F	
Between infinity and 2F	Real, inverted, diminished ($m < -1$), between F and 2F	
At 2F	Real, inverted, equal in size, ($m = -1$) at 2F	
Between 2F and F	Real, inverted, enlarged ($m > -1$), between 2F and ∞	
At F	Real, inverted, enlarged ($m >> -1$), at infinity	
Between focus F and Pole P	Virtual, erect, enlarged ($m > +1$), between ∞ and image, on same side of object	

(b) For Divergent or Concave lens

1. If object is at infinity image will be formed at focus on the same side of the lens as the object, virtual, erect and point sized.
2. If object is in front of lens, anywhere between the optical centre and infinity image will be formed between focus and the optical centre, on the same side of the lens, highly diminished, virtual and erect.

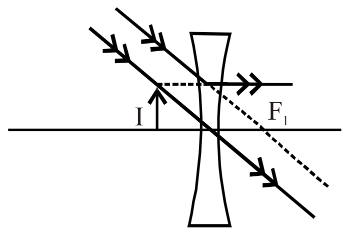


Fig. 1.53 (a)

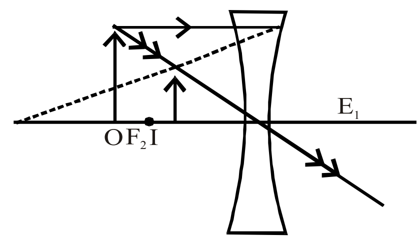


Fig. 1.53 (b)

CHECK Point

The diagram shows an object *OA* and its image IB formed by a lens. Complete the ray diagram and locate the focus of the lens by labelling as *F*. State whether the lens is convex or concave ?

Fig. 1.54

SOLUTION

The completed ray diagram is given below.

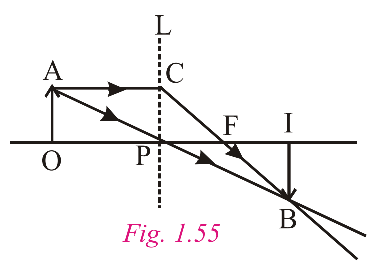


Fig. 1.55

Since the image is inverted and magnified, the lens is convex.

LENS FORMULA

If an object is placed at a distance u from the optical centre 'O' of a lens and its images is formed at a distance v (from the optical centre) and focal length of this lens is f then $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$ this relationship is known as Lens formula

Proof : Consider an object AB placed beyond $2F$ infront of a convex lens. A real, inverted and smaller image is formed between F and $2F$ on the other side of the lens. Applying sign convention, we obtain.

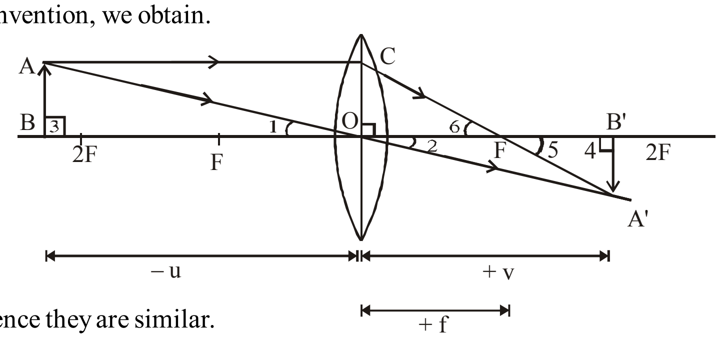


Fig. 1.56

(Object distance) $OB = -u$

(Image distance) $OB' = +v$

(Focal length) $OF = +f$

In $\Delta\, ABO$ and $\Delta\, A'B'O$,

$\angle 1 = \angle 2$ (Vertically opposite angles)

$\angle 3 = \angle 4$ (Each 90°)

$\therefore\ \angle BAO \sim \angle B'A'O$ (By AA similarity)

Therefore, $\Delta\, ABO$ and $\Delta\, A'B'O$ are equiangular and hence they are similar.

$$\therefore\ \frac{A'B'}{AB}=\frac{OB'}{OB}=\frac{+v}{-u} \Rightarrow \frac{A'B'}{AB}=\frac{+v}{-u} \quad ...(1)$$

Now $\Delta\, OCF$ and $\Delta\, A'B'F$ are also equiangular, hence similar.

In particular, $\frac{A'B'}{OC}=\frac{FB'}{OF}$ But $OC = AB$.

$\therefore \frac{A'B'}{AB} = \frac{FB'}{OF}$

Since All distances are measured from optical centre, therefore,

$$\frac{A'B'}{AB} = \frac{FB'}{OF} = \frac{OB' - OF}{OF} = \frac{+v-(+f)}{+f} = \frac{v-f}{f} \quad \text{...(2)}$$

Now comparing eq. (1) and (2), $\frac{+v}{-u} = \frac{v-f}{f} \Rightarrow fv = -uv + fu$

Dividing both sides by uvf, $\frac{1}{u} = -\frac{1}{f} + \frac{1}{v} \Rightarrow \mathbf{\frac{1}{f} = \frac{1}{v} - \frac{1}{u}}$ **(Lens formula)**

Similarly, we can prove the lens formula for a concave lens.

MAGNIFICATION

If a thin object of linear size O situated vertically on the axis of a lens at a distance u from the optical centre and its image of size I is formed at a distance v (from the optical centre) then magnification (transverse) is defined as

Magnification, $m = \frac{I}{O} = \frac{v}{u}$

Magnification m can be negative or positive.

Negative magnification implies that image is inverted with respect to object while positive magnification means that image is erect with respect to object.

Other formulae of magnification $m = \frac{f}{f+u}$, $m = \frac{f-v}{f}$

For real extended object, if the image formed by a single lens in inverted (i.e., m is negative) it is always real and the lens is convergent i.e., convex.

ILLUSTRATION : 1.24

Two converging lenses with focal lengths 15 cm and 25cm are placed 18cm apart. An object is located 8.0 cm to the left of the 15cm focal length lens. Where is the final image formed ?

SOLUTION :

Find the image location for the first lens using the lens formula, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

$$\frac{1}{v_1} = \frac{1}{f_1} - \frac{1}{u_1} = \frac{1}{15\text{cm}} - \frac{1}{8.0\text{cm}} \qquad \text{which gives } v_1 = -17\text{cm}$$

This image forms the object of the second lens located 17 cm + 18 cm = 35 cm away. Then for the second lens

$$\frac{1}{v_2} = \frac{1}{f_2} - \frac{1}{u_2} = \frac{1}{25\text{ cm}} - \frac{1}{35\text{ m}} \qquad \text{which gives } v_2 = 87.5\text{ cm}$$

The final image lies 87.5 cm to the right of the second lens (25 cm) lens.

ILLUSTRATION : 1.25

A converging lens is used to read the small print. The lens is held 9.0 cm from the print and produces a magnitification of +2.5. What is the focal length of the lens ?

SOLUTION :

The fine print serves as the object for the lens $u = 9.0$ cm. The image distance is then

$$v = -mu = -(2.5\text{ cm})(9.0\text{ cm}) = -22\text{ cm}$$

The thin lens equation gives $\frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \frac{1}{9.0\text{ cm}} + \frac{1}{(-22\text{ cm})}$

so $f = +15$ cm.

ILLUSTRATION : 1.26

An object is placed at a distance of 1.50 m from a screen and a convex lens placed in between produces an image magnified 4 times on the screen. What is the focal length and the position of the lens?

SOLUTION :

Here, magnification $m = \frac{I}{O} = -4$

Let lens is placed at a distance of x from the object. Then
$u = -x$, and $v = (1.5 - x)$

using $m = \frac{v}{u}$, we get $\quad -4 = \frac{1.5 - x}{-x}$

or $\quad 4x = 1.5 - x \quad$ or $\quad 5x = 1.5$
Thus $\quad x = 0.3$ metre
The lens is placed at a distance of 0.3 m from the object (or 1.20 m from the screen)

For focal length, we may use $\quad m = \frac{f}{f+u}$

or $\quad -4 = \frac{f}{f+(-0.3)} \quad$ or $\quad -4f + 1.2 = f$ or $5f = 1.2$

Thus $\quad f = \frac{1.5}{5} = 0.24$
The focal length is 0.24 m (or 24 cm)

ILLUSTRATION : 1.27

A lens placed at a distance of 20 cm from an object produces a virtual image 2/3 the size of the object. Find the position of the image, kind of lens and its focal length.

SOLUTION :

Virtual image means, I is positive and it is given that $I = \frac{2}{3}$ O. Thus, m $= \frac{\mathrm{I}}{\mathrm{O}} = +\frac{2}{3}$

Further because $u = -20$ cm (given), using $\quad m = \frac{f}{f+u}$

we get, $\quad \frac{2}{3} = \frac{f}{f+(-20)} \quad$ or $\quad f = -40$ cm

The f is negative, thus the lens is a concave lens. Again using $\quad m = \frac{v}{u}$

we get $\quad \frac{2}{3} = \frac{v}{-20} \quad$ or $\quad v = -\frac{2}{3} = -1.33$ cm
The virtual image is on the same side of the object.

CONNECTING TOPIC

LENS MAKER FORMULA

This formula gives a relation among the focal length (f), the refractive index of a lens with respect to the medium in which it is placed $\left({}_m\mu_\ell\right)$ and its radii of curvatures (R_1 and R_2). This formula is expressed as

$$\frac{1}{f} = \left({}_m\mu_\ell - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad \text{or} \quad \frac{1}{f} = \left(\frac{{}_a\mu_\ell}{{}_a\mu_m} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

where, $\quad {}_a\mu_\ell$ = refractive index of lens with respect to air.
$\quad {}_a\mu_m$ = refractive index of lens with respect to air.
$\quad R_1$ = radius of curvature of first surface of lens.
$\quad R_2$ = radius of curvature of second surface of lens.
If lens is placed in air, then

$${}_a\mu_m = 1 \text{ and } {}_a\mu_\ell = \mu \text{ (say)}$$

$$\therefore \frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

COMBINATION OF LENSES

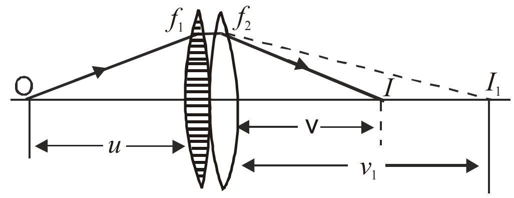


Fig.1.57

Case I : When two thin lenses are in contact.
In case of two thin lenses in contact if the first lens of focal length f_1 forms the image I_1 (of an object) at a distance v_1 from it,

$$\frac{1}{v_1}-\frac{1}{u}=\frac{1}{f_1} \qquad ...(1)$$

Now the image I_1 will act as object for second lens and if the second lens forms image I at a distance v from it,

$$\frac{1}{v}-\frac{1}{v_1}=\frac{1}{f_2} \qquad ...(2)$$

Adding equations (1) & (2) $\frac{1}{v}-\frac{1}{u}=\frac{1}{f_1}+\frac{1}{f_2}$ or $\frac{1}{v}-\frac{1}{u}=\frac{1}{F}$ with $\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2}$

i.e. the combination behaves as a single lens of equivalent focal length F given by

$$\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2} \quad \text{or} \quad P=P_1+P_2$$

Case II : When two thin lenses are separated by a certain distance.
If the two thin lens are separated by a distance d apart, then F is given by

$$\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2}-\frac{d}{f_1f_2}$$

so $P=P_1+P_2-P_1P_2d.$

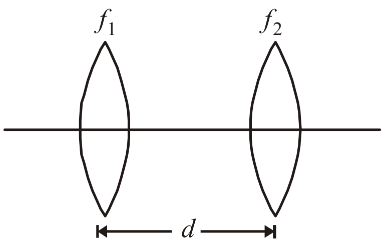


Fig. 1.58

NOTE : (1) If two thin lenses of equal focal length but of opposite nature (i.e. one convergent and other divergent) are put in contact, the resultant focal length of the combination will be

$\frac{1}{F}=\frac{1}{+f}+\frac{1}{-f}=0$ i.e, $F=\infty$ and $P=0$ i.e., the system will behave as a plane glass plate.

(2) If two thin lens of same nature are put in contact then as

$$\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2}$$

$\frac{1}{F}>\frac{1}{f_1}$ and $\frac{1}{F}>\frac{1}{f_2}$ i.e. $F<f_1$ and $F<f_2$

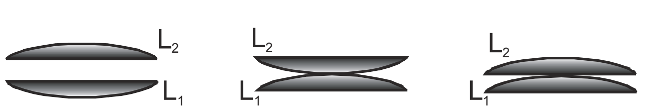
i.e. the resultant focal length will be lesser than smallest individual.

(3) If two thin lenses of opposite nature with different focal lengths are put in contact the resultant focal length will be of same nature as that of the lens of shorter focal length but its magnitude will be more than that of shorter focal length.

If a lens of focal length f is divided into two equal parts as in figure (A)

each part has a focal length f′ then as $\frac{1}{f}=\frac{1}{f'}+\frac{1}{f'}$ $\qquad f'=2f$

i.e. each part have focal length 2f now if the se parts are put in contact as in (B) or (C), the resultant focal length of the combination will be $\frac{1}{F}=\frac{1}{2f}+\frac{1}{2f}$ i.e. $F=f\,(=\text{initial value})$



(a) (b) (c)

Fig. 1.59

SILVERING OF LENS

A lens has two surfaces. If one of the surfaces is silvered, the lens behaves as a mirror. The mechanism of the image formation can be understood in brief as given below.

Light from the object falls on the lens which produces a virtual image I_1. This image acts as object for the silvered surface (which acts as a mirror) and a second virtual image I_2 is formed. Finally, this image acts as object for the lens and final image I_3 is formed. Thus, refraction takes place two times at the lens and reflection takes one time at the mirror.

Thus, on silvering the lens behaves as a mirror of focal length F given by

$$\frac{1}{F}=\frac{2}{F_\ell}+\frac{1}{F_m} \qquad \ldots\ldots (1)$$

where F_ℓ = focal length of lens from which refraction take place two times.
F_m = focal length of mirror from which reflection takes place one time.

Case I : When a double convex lens is silvered.

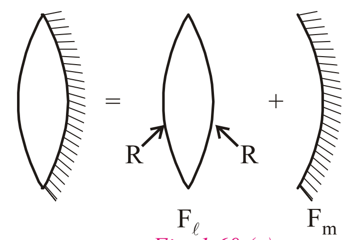


Fig. 1.60 (a)

Clearly, $F_m=\frac{R}{2}$

Also, by lens maker formula,

$$\frac{1}{F_\ell}=(\mu-1)\left(\frac{1}{R}+\frac{1}{R}\right)=(\mu-1).\frac{2}{R} \qquad \therefore \qquad F_\ell=\frac{R}{2(\mu-1)}$$

Putting the values of F_m and F_ℓ in (1), we get

$$\frac{1}{F}=\frac{2\times 2(\mu-1)}{R}+\frac{2}{R}=\frac{2(2\mu-1)}{R} \qquad \therefore \qquad F=\frac{R}{2(2\mu-1)}$$

Case II : When a plane convex lens is silvered.

(i) If curved surface is silvered

In this case,

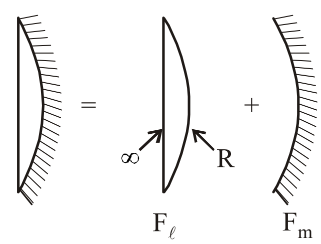


Fig. 1.60 (b)

$$F_m=\frac{R}{2} \quad \text{and} \quad F_\ell=\frac{R}{\mu-1}$$

$$\therefore \qquad F=\frac{R}{2\mu}$$

(ii) **If plane surface is silvered.**

In this case, $F_m=\infty$ $(\because\ R=\infty)$

and $F_\ell=\frac{R}{\mu-1}$

$$\therefore \qquad F=\frac{R}{2\,(\mu-1)}$$

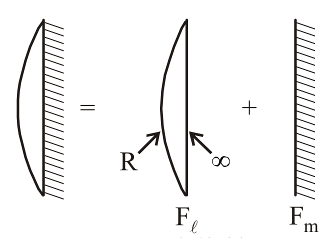


Fig. 1.60 (c)

POWER OF A LENS

If focal length of a lens is measured in metre (m) then its reciprocal gives the power (P) of the lens.

i.e., Power of a lens, $P=\frac{1}{f\,(\text{in m})}$

The **S.I. unit** of power is diopter (D).

Power of a combination of lenses: If a number of lenses are placed in close contact with each other, then the power of the combination of lenses is equal to the algebraic sum of the powers of individual lenses. i.e. $P = P_1 + P_2 + \ldots.P_n$

ILLUSTRATION : 1.28

A doctor has prescribed a corrective lens of power +1.5 D. Find the focal length of the lens. Is the prescribed lens diverging or converging?

SOLUTION :

Given: $P = +1.5\,D$

Focal length $f = \frac{100}{P}\text{cm} = \frac{100}{1.5} = \frac{1000}{15} = +66.67\text{ cm} = +0.67\text{m}$

As the focal length is + *ve*, hence it is a converging or convex lens.

ILLUSTRATION : 1.29

A convex lens of focal length 20 cm is placed in contact with concave lens of focal length 60 cm. Calculate : (a) power of each of the lens (b) power of combination (c) focal length of combination (d) nature of combination.

SOLUTION :

As we know, power of alens $P = \frac{1}{f(\text{in metre})}$

(a) Power of convex lens $= \frac{100}{20} = +5\text{D}$ Power of concave lens $= \frac{100}{60} = -1.67\text{ D}$

(b) Power of combination $P = P_1 + P_2 = (+5D) + (-1.67D) = +3.33\,D$

(c) Focal length of combination

$$f(\text{in cm}) = \frac{100}{P} = \frac{100}{3.33} = +30.0\text{ cm}$$

(d) As power of combination is positive, therefore, combination behaves like a convex lens.

ILLUSTRATION : 1.30

A convex lens of focal length 10.0 cm is placed in contact with a convex lens of 15.0 cm focal length. What is the focal length of the combination.

SOLUTION :

For combination of lenses

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{10} + \frac{1}{15} = \frac{25}{150} = \frac{1}{6}$$

Therefore, $f = 6$ cm

ILLUSTRATION : 1.31

Ten identical converging thin lenses, each of focal length 10 cm, are in contact. What is the power of the combined lens.

SOLUTION :

For thin lenses in contact

$P = P_1 + P_2 + \ldots\ldots\ldots\ldots\ldots\ldots$

$$= 10\,P_1 = \frac{10 \times 100}{10} = 100\text{ D}$$

ILLUSTRATION : 1.32

The radius of curvature of a thin plano-convex lens is 10 cm (of curved surface) and the refractive index is 1.5. If the plane surface is silvered, then it behaves like a concave mirror of focal length

(a) 10 cm (b) 15 cm (c) 20 cm (d) 5 cm

SOLUTION :

(a) The silvered plano convex lens behaves as a concave mirror; whose focal length is given by

$$\frac{1}{F} = \frac{2}{f_1} + \frac{1}{f_m}$$

If plane surface is silvered

$$f_m = \frac{R_2}{2} = \frac{\infty}{2} = \infty$$

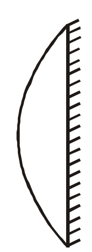


Fig. 1.61

$$\therefore \frac{1}{f_1} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = (\mu - 1)\left(\frac{1}{R} - \frac{1}{\infty}\right) = \frac{\mu - 1}{R}$$

$$\therefore \frac{1}{F} = \frac{2(\mu - 1)}{R} + \frac{1}{\infty} = \frac{2(\mu - 1)}{R}$$

$$F = \frac{R}{2(\mu - 1)}$$

Here, $R = 10$ cm, $\mu = 1.5$

$$\therefore F = \frac{10}{2(1.5 - 1)} = 10\text{cm}$$

CONNECTING TOPIC

INTERFERENCE, DIFFRACTION AND POLARISATION OF LIGHT

Interference of Light

The colours in soap bubbles and oil slicks are due to this property of light. When two light waves of exactly same frequency travels in a medium, in the same direction simultaneously then due to their superposition, the intensity of light is maximum at some points while the intensity is minimum at some other points. This phenomenon is called interference of light. It is of two types :

(i) Constructive interference and

(ii) Destructive interference

When the waves meet a point with same phase, constructive interference is obtained at that point. Hence, at that point bright spot of light is seen.

But when the waves meet a point with opposite phase, destructive interference is obtained at that point. Hence, at that point dark spot of light is seen.

Diffraction of Light

The wavelength of light is of the order of angstroms. So, when light waves encounter obstacles of very small sizes, the light waves bend around the edges of the obstacle and travel. This is known as diffraction of light. It is due to the diffraction of light that a sharp shadow of an object cannot be obtained on any screen placed behind it. Due to diffraction, light bends and travels into the region of geometrical shadow of the object and thus complete darkness is not found in the shadow. The brightness of light gradually decreases towards complete darkness as we go gradually into the geometrical shadow of the obstacle.

Polarisation of Light

An ordinary source of light such as bulb consists of a large number of waves emitted by atoms or molecules in all directions symmetrically. Such light is called unpolarized light (Fig. 1.62 (a))

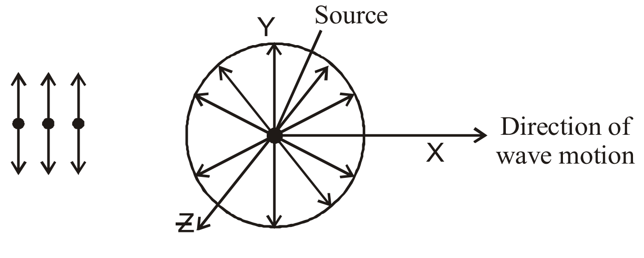


Fig.1.62 (a) Unpolarised light

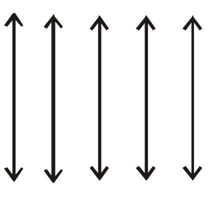
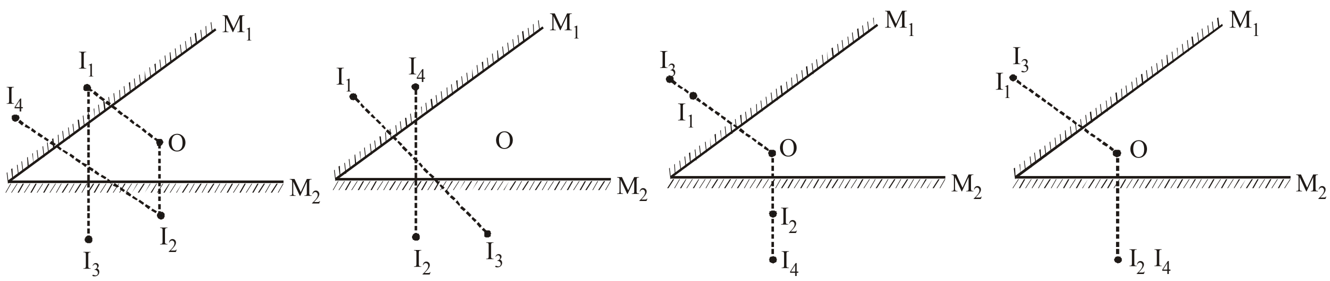


Fig.1.62 (b) Polarised light

If we confine the direction of wave vibration of electric vector in one direction (with the help of polaroids or Nicol prism) perpendicular to the direction of wave propagation, then such type of light is called plane polarised or linearly polarised. The phenomenon by which, we restrict the vibrations of wave in a particular direction (fig.1.62 (b) perpendicular to direction of wave propagation is called polarisation.

MISCELLANEOUS SOLVED EXAMPLES

1. Two plane mirrors are inclined at an angle of 30º. Then the first four images of an object O placed between the two mirrors are correctly represented by



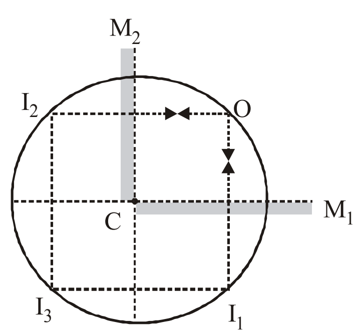
(1) (2) (3) (4)

Sol. The image of object O from mirror M_1 is I_2 and the image of I_1 (the virtual object) from mirror M_2 is I_3. The image of object O from mirror M_2 is I_2 and the image of I_2 (the virtual object) from mirror M_1 is I_4. Notice that this interpretation, according to ray diagram rules, is valid only for Fig. (1). All others are inconsistent. Hence (1) is correct.

2. Find the number of images formed by two mutually perpendicular plane mirrors.

Sol. Here, $n = \dfrac{360^\circ}{\theta} = \dfrac{360^\circ}{90} = 4$

$\therefore$ n is an even number



Thus, number of images formed $= n - 1 = 3$. All these three images lie on a circle with centre at C (The point of intersection of mirrors M_1 and M_2) and whose radius is equal to the distance between C and object 'O'.

3. The focal length of a concave mirror is 30 cm. Find the position of the object in front of the mirror, so that the image is three times the size of the object.

Sol. Here image can be real or virtual. If the image is real

$f = -30$, $u = ?$, $m = -3$

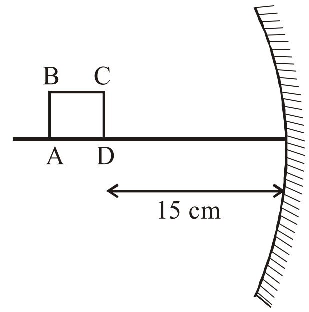
Magnification $m = \dfrac{f}{f-u} \Rightarrow -3 = \dfrac{-30}{-30-u} \Rightarrow u = -40$ cm.

If the image is virtual

$m = \dfrac{f}{f-u} \Rightarrow 3 = \dfrac{-30}{-30-u} \Rightarrow u = -20$ cm.

4. A square ABCD of side 1mm is kept at distance 15 cm infront of the concave mirror as shown in the figure. The focal length of the mirror is 10 cm. Find the length of the perimeter of its image.

Sol. Given: $u = 15$ cm, f = 10 cm $\therefore$ $v = -30$, [using $\dfrac{1}{v} = \dfrac{1}{f} - \dfrac{1}{u}$]



$m = -\frac{v}{u} = -2$

$\therefore\ A'B' = C'D' = 2 \times 1 = 2\text{mm}$

Now $\frac{B'C'}{BC} = \frac{A'D'}{AD} = \frac{v^2}{u^2} = 4 \Rightarrow B'C' = A'D' = 4$ mm

$\therefore$ Length = 2 + 2 + 4 + 4 = 12 mm

5. An object of length 1 cm is placed at a distance of 15 cm from a concave mirror of focal length 10 cm. Find the nature and size of the image.

Sol. Given: u = – 15 cm, f = – 10 cm, O = 1 cm

$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \Rightarrow \frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{-10} - \frac{1}{-15}$

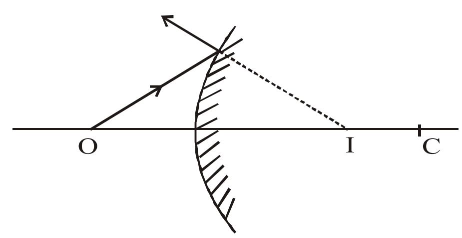
$\therefore\ v = -30$ cm $\qquad \frac{I}{O} = -\frac{v}{u} = -\frac{-30}{-15} = -2$

$I = -2 \times 1 = -2$ cm $\qquad$ Image is inverted and on the same side (real) of size 2 cm.

6. A convex mirror has its radius of curvature 20 cm. Find the position of the image of object placed at a distance of 12 cm from the mirror.

Sol. The situation is shown in figure.

Here $u = -12$ cm and $R = +20$ cm. We have



$\frac{1}{u} + \frac{1}{v} = \frac{2}{R}$ or $\frac{1}{v} = \frac{2}{R} - \frac{1}{u}$

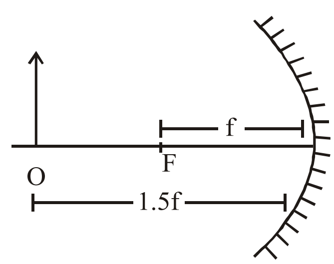
$\Rightarrow \frac{1}{v} = \frac{2}{20}\text{ cm} - \frac{1}{-12}\text{ cm} = \frac{11}{60}\text{ cm}$

$\therefore\ v = \frac{60}{11}$ cm

7. An object of length 2.5 cm is placed at a distance of 1.5 *f* from a concave mirror where *f* is the magnitude of the focal length of the mirror. The length of the object is perpendicular to the principal axis. Find the length of the image. Is the image erect or inverted?

Sol. The given situation is shown in figure.

The focal length $f = -f$ and $u = -1.5f$, we have



$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \qquad$ or $\qquad -\frac{1}{1.5f} + \frac{1}{v} = -\frac{1}{f}$

or $\frac{1}{v} = \frac{1}{1.5f} - \frac{1}{f} = \frac{-1}{3f}$ $\quad$ or $\quad v = -3f$

Now $m = -\frac{v}{u} = \frac{3f}{-1.5f} = -2 \quad$ or $\quad \frac{h_2}{h_1} = -2$

or $h_2 = -2h_1 = -5.0$ cm

The length of image is 5.0 cm. The minus sign shows that it is inverted.

8. An object is situated at a distance of *f*/2 from a convex lens of focal length *f*. Find the distance of image.

Sol. For a spherical lens, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

For convex lens, $u = -f/2$ and f is + ve

$\therefore\ \frac{1}{v} = \frac{1}{f} + \frac{1}{u} = +\frac{1}{f} - \frac{2}{f} = -\frac{1}{f} \qquad \therefore \qquad v = -f$

9. A lens placed at a distance of 20 cm from an object produces a virtual image 2/3 the size of the object. Find the position of the image, kind of lens and its focal length.

Sol. Virtual image means, I is positive and it is given that $I = (2/3)O$. Thus, magnification $m = +2/3$

Further because $u = -20$ cm (given), using

$$m = \frac{f}{f+u} \quad \text{we get, } \frac{2}{3} = \frac{f}{f+(-20)} \quad \text{or} \quad f = -40 \text{ cm}$$

The f is negative, thus the lens is a concave lens. Again using $m = v/u$

$$\text{we get } \frac{2}{3} = \frac{v}{-20} \quad \text{or } v = -\frac{2}{3} = -1.33 \text{ cm}$$

The virtual image is on the same side of the object.

10. An object is placed at a distance of 50 cm from a concave lens of focal length 20 cm. Find the nature and position of the image.

Sol. Here, object distance, $u = -50$ (object on the left of the lens)

Focal length, $f = -20$ cm (focus on the left of the lens)

Image distance, $v = ?$

From lens formula, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

We have, $\frac{1}{v} = \frac{1}{f} + \frac{1}{u}$

Putting values, we get $\frac{1}{v} = \frac{1}{-20} + \frac{1}{-50} = \frac{-5-2}{100} = \frac{-7}{100}$ or $v = -\frac{100}{7}$ cm $= -14.3$ cm.

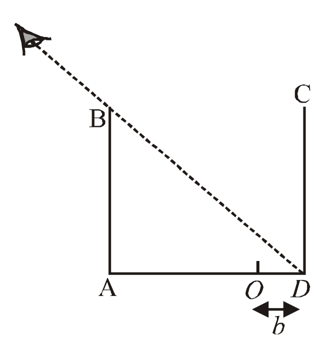
Image is formed at distance 14.3 cm on the left of the lens.

From relation, $m = \frac{h_2}{h_1} = \frac{v}{u}$ we have, $h_2 = h_1 \frac{v}{u}$

Putting values, we get $h_2 = h_1 \times \frac{-100/7}{-50} = +\frac{2}{7} h_1$

Since h_1 is positive (erect object), h_2 is also positive. The image is erect and virtual.

11. A cubical vessel with opaque walls, is so placed that the eye of an observer cannot see its bottom but can see the entire wall CD. A small object is placed at O at a distane b = 10 cm from corner D. What minimum depth of water $\left(\mu = \frac{4}{3}\right)$ should be poured into the vessel which will enable the observer to see the object?



Sol. Let minimum depth of water be x. Since the vessel is cubical (AB = AD), it is clear that angle $i = 45°$. From Snell's law, the angle of refraction is given by

$\sin r = \frac{\sin i}{n} = \frac{\sin 45^\circ}{4/3} = 0.5303$ $\quad\therefore\; r = 32.03^\circ$

Since $\angle$ QPD = 45°, PQ = x = QD

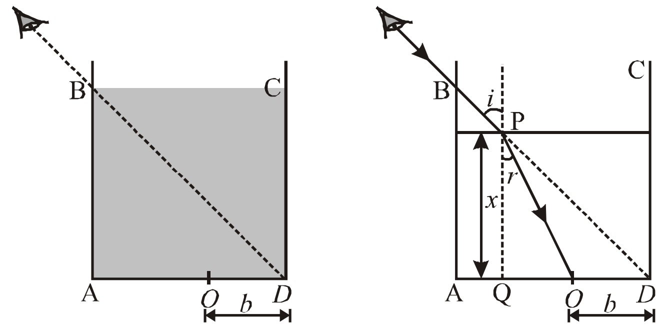
Hence, QO = $x - b$

Now, ΔPQO, QO = $x \tan r$

$\Rightarrow\; x - b = x\tan r \Rightarrow\; x = \frac{b}{1-\tan r}$

Substituting for b and r, we get

x = 26.7 cm



12. A convex lens forms a real and inverted image of a needle at a distance of 25 cm from the lens. If the image of the same size as that of the needle, then where should the needle be placed in front of the lens. Also calculate the power of the lens.

Sol. Step 1. We know, if the size of the real and inverted image is same as that of the object, then the object is at 2F and image is also formed at 2F on the other side of the convex lens.

$\therefore\; u = -25$cm

Also $\frac{h_2}{h_1} = \frac{v}{u}$ or $\frac{v}{u} = 1$ $\qquad (\because h_2 = h_1)$

or $v = u = 25$ cm

Using $-\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$, we get

$\frac{1}{f} = \frac{1}{25} + \frac{1}{25} = \frac{2}{25}$ or $\quad f = \frac{25}{2} = 12.5$cm

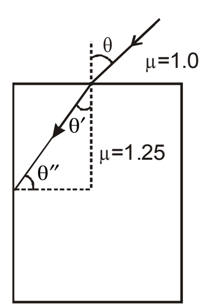
In this case, $2f$ = 25 cm $\quad$ or $\quad f$ = 12.5 cm

Thus, needle must be placed at a distance of 25 cm in front of the convex lens.

Step 2. Now, power of lens, $P = \frac{100}{f\,(\text{in cm})} = \frac{100}{12.5} = +8.0$ D

SOLVED EXAMPLES BASED ON CONNECTING TOPICS

13. Consider the situation shown in figure. Find maximum angle for which the light suffers total internal reflection at the vertical surface.



Sol. The critical angle for this case is $\theta'' = \sin^{-1}\frac{1}{1.25} = \sin^{-1}\frac{4}{5}$ *or* $\sin\theta'' = \frac{4}{5}$

Since $\theta'' = \frac{\pi}{2} - \theta'$, we have $\sin\theta' = \cos\theta'' = \frac{3}{5}$

From Snell's law,

$\frac{\sin\theta}{\sin\theta'} = 1.25$ *or* $\sin\theta = 1.25\times\sin\theta' = 1.25\times\frac{3}{5} = \frac{3}{4}$ *or* $\theta = \sin^{-1}\frac{3}{4}$

If θ'' is greater than the critical angle, θ will be smaller than this value. Thus, the maximum value of q' for which total internal reflection takes place at the vertical surface is $\sin^{-1}$ (3/4).

14. A converging lens has a focal length of 20 cm in air. It is made of a material of refractive index 1.6. If the lens is immersed in a liquid of refractive index 1.3. What will be the new focal length of the lens?

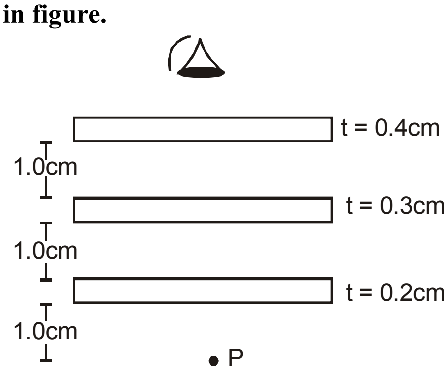
Sol. $\frac{1}{f_1} = (\mu_1 - 1)\frac{2}{R}$ $\qquad \mu_1 = 1.6, f_1 = 20$

$\frac{1}{f_1} = (1.6-1)\frac{2}{R}$ $\qquad$ or $\quad \frac{1}{20} = \frac{0.6\times 2}{R} \therefore R = \frac{0.6\times 2\times 20}{10} = 24\text{cm}$

$\frac{1}{f_2} = (\mu_1 - 1)\times\frac{2}{R} \quad \therefore \quad \frac{1}{f_2} = (\frac{1.6}{1.3} - 1) = \frac{2}{R}$

$\frac{1}{f_2} = (\frac{1.6-1.3}{1.3})\frac{2}{24} = \frac{0.3}{1.3}\times\frac{1}{12} = \frac{1}{52}$ $\qquad$ or, $\quad f_2 = 52$ cm.

15. Locate the image of the point *P* as seen by the eye through the slabs of refrective index (*m* = 1.2, 1.3, 1.4 respectively starting from the bottom) as shown in figure.



Sol. The net shift from one slab is $t\left(1-\frac{1}{\mu}\right)$ where t is the thickness of slab, μ is the refractive index of slab.

Total shift $t_1\left(1-\frac{1}{\mu_1}\right) + t_2\left(1-\frac{1}{\mu_2}\right) + t_3\left(1-\frac{1}{\mu_3}\right) = 0.2\left(1-\frac{1}{1.2}\right) + 0.3\left(1-\frac{1}{1.3}\right) + 0.4\left(1-\frac{1}{1.4}\right)$

$= 0.2\left(\frac{0.2}{1.2}\right) + \frac{0.3\times 0.3}{1.3} + \frac{0.4\times 0.4}{1.4}$

$= 0.0333 + 0.0692 + 0.114 = 0.2$ cm above point P.

16. A lens has a power of + 5 diopter in air. What will be its power if completely immersed in water ? Given: $\mu_g = \frac{3}{2}; \mu_w = \frac{4}{3}$

Sol. Let f_a and f_w be the focal lengths of the lens in air water respectively, then

$P_a = \frac{1}{f_a}$ $\qquad$ and $\qquad P_w = \frac{\mu_w}{f_w}$; $f_a = 0.2$ m $= 20$ cm

Using lens maker's formula

$$P_a = \frac{1}{f_a} = (\mu_g - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \qquad \text{...(i)}$$

$$\frac{1}{f_w} = \left(\frac{\mu_g}{\mu_w} - 1\right)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

$$\Rightarrow P_w = \frac{\mu_w}{f_w} = (\mu_g - \mu_w)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \qquad \text{...(ii)}$$

Dividing equation (ii) by equation (i), we get,

$$\frac{P_w}{P_a} = \frac{(\mu_g - \mu_w)}{(\mu_g - 1)} = \frac{1}{3} \quad \text{or} \quad P_W = \frac{P_a}{3} + \frac{+5}{3}D$$

1 EXERCISE

Fill in the Blanks :

DIRECTIONS : *Complete the following statements with an appropriate word / term to be filled in the blank space(s).*

1. The power of a convex lens is .... and that of a concave lens is ....
2. Light seems to travel in ....
3. A light ray travelling obliquely from a denser medium to a rarer medium bends .... the normal. A light ray bends .... the normal when it travels obliquely from a rarer to a denser medium.
4. In case of a rectangular glass slab, the refraction takes place at both .... interface and .... interface. The emergent ray is .... to the direction of incident ray.
5. Power of a lens is the reciprocal of its ....
6. The SI unit of power of a lens is ....
7. The angle of incidence is .... to the angle of reflection.
8. The reflecting surface of a spherical mirror may be curved .... or ....
9. The surface of the spoon can be approximated to a .... mirror.
10. The centre of the reflecting surface of a spherical mirror is a point called the ....
11. The centre of curvature of a concave mirror lies in .... of it.
12. Line passing through the pole and the centre of curvature of a spherical mirror is called the ....
13. A ray parallel to the principal axis, after reflection, will pass through the ....
14. The dentists use .... mirrors to see large images of the teeth of patients.
15. A transparent material bound by two surfaces, of which one or both surfaces are spherical, forms a ....
16. The degree of .... of light rays achieved by a lens is expressed in terms of its power.
17. An object is placed in front of a spherical mirror. The image is found to be virtual for all positions of the object. The spherical mirror is ....
18. Two immiscible transparent liquids A and B have 1.2 and 1.5 as their refractive indices (with respect to air). The refractive index of B with respect to A is ....

True / False :

DIRECTIONS : *Read the following statements and write your answer as true or false.*

1. The reflecting surfaces, of all types, obey the laws of reflection.
2. Light travels in vacuum with an enormous speed of 3×10^8 ms^{-1}.
3. The speed of light is different in different media.
4. The refractive index of a transparent medium is the ratio of the speed of light in vacuum to that in the medium.
5. The incident ray, the normal to the mirror at the point of incidence and the reflected ray, all lie in the same plane.
6. Image formed by a plane mirror is always virtual and erect.
7. The principal focus of a spherical mirror lies midway between the pole and centre of curvature.
8. Convex mirrors enable the driver to view much larger area than would be possible with a plane mirror.
9. A concave lens will always give a virtual, erect and diminished image.
10. A ray of light passing through the optical centre of a lens will emerge without any deviation.
11. A plane mirror can form virtual images.
12. An object is placed in front of a mirror and an image of it is formed at the object itself. The mirror mentioned in question is a convex mirror.
13. A concave mirror can produce both real and virtual images.
14. Light travels faster in glass than in air.
15. Light has transverse wave nature.
16. The laws of reflection are valid for plane mirrors and not for spherical mirrors.
17. The mirror formula is valid only if the aperture of the mirror is small.
18. When a ray of light travels from air to water, its speeds up.
19. A lens that is thicker at the middle than at the edges is a diverging lens.

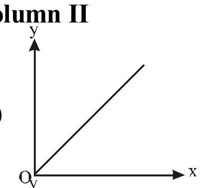
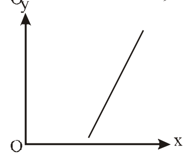
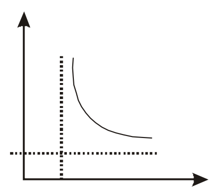
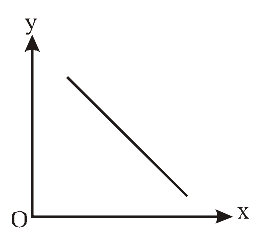
Match the Following :

DIRECTIONS : *Each question contains statements given in two columns which have to be matched. Statements (A, B, C, D) in column I have to be matched with statements (p, q, r, s) in column II.*

1. Match the following :

Column I	Column II
(A) Power of convex mirror	(p) Positive power
(B) Power of concave mirror	(q) Negative power
(C) Power of plane mirror	(r) Zero power
(D) Power of convex lens	(s) Infinite power

2. The graphs given apply to convex lens of focal length f, producing a real image at a distance v from the optical centre when self luminous object is at distance u from the optical centre. The magnitude of magnification is m. Identify the following graphs with the first named quantity being plotted along y-axis.

Column I	Column II
(A) v against u	(p) 
(B) $\frac{1}{v}$ against $\frac{1}{u}$	(q) 
(C) m against v	(r) 
(D) $(m+1)$ against $\frac{v}{f}$	(s) 

Very Short Answer Questions :

DIRECTIONS : *Give answer in one word or one sentence.*

1. Define refraction.
2. What is the relation between focal length and radius of curvature?
3. What is reflection of light?
4. A man is moving towards a plane mirror at the speed of 8 cm/sec. What is the relative speed of man towards his image?
5. According to sign conventions for mirrors what sign is given to image distance?
6. Magnification of a mirror is always less than 1, which mirror is this?
7. Refractive indices of benzene and kerosene oil are 1.5 and 1.4 respectively. Which is optically denser?
8. What do you understand by optically denser and optically rarer medium?
9. What is the relation between ${}_1n_2$ and ${}_2n_1$?
10. For the same angle of incidence; the angle of refraction in three different media A, B and C are 150°; 25° and 35° respectively. In which medium velocity of light will be minimum?
11. Which lens is known as converging and which is known as diverging lens?
12. For what position convex lens form real, inverted and diminished image?
13. Is it possible to form a real image by using a real object with a concave lens ?
14. Which phenomenon is responsible for
    (i) Twinkling of star, (ii) Sparkling of diamond?
15. Sun can been seen 2 minutes before actual sun rise and 2 minutes after actual sun set. Why?

Short Answer Questions :

DIRECTIONS : *Give answer in 2 to 3 sentences.*

1. Prove that the refractive index of glass with respect to air is the reciprocal of the refractive index of air with respect to glass.
2. What is dispersion of light and what is its cause?
3. A concave mirror produces three times magnified (enlarged) real image of an object placed at 10 cm in front of it. Where is the image located?
4. Light enters from air to glass having refractive index 1.50. What is the speed of light in the glass? The speed of light in vacuum is 3×10^8 ms^{-1}.
5. Find the power of a concave lens of focal length 2 m.
6. Find the focal length of a lens of power –2.0 D. What type of lens is this ?
7. A convex lens is of focal length 10 cm what is its power?
8. Under what condition will a concave mirror produce an erect image? A virtual image ? An image smaller than the object? An image larger than the object?
9. A boy is standing in front of plane mirror finds his image at a distance of 20m from himself. Find the distance between boy and mirror.
10. An object is placed at a distance of 10 cm from a concave mirror of focal length 20 cm. Find the image distance and nature of image.
11. Refractive index of glass for light of yellow, green and red colours are μ_y, μ_g and μ_r respectively. Rearrange these symbols in the increasing order of values.
12. Give the ratio of velocities of light rays of wavelengths 4000 Å and 8000 Å.
13. An object is placed at a distance of 12 cm in front of a concave mirror. It forms a real image four times larger than the object. Calculate the distance of the image from the mirror.
14. With respect to air, the refractive index of ice is 1.31 arid that of rock salt is 1.54. Calculate the refractive index of rock salt with respect to ice.
15. Light enters from air into glass plate which has a refractive index of 1.50. Calculate the speed of light in glass. The speed of light in air is 3×10^8 ms^{-1}.
16. A concave mirror and a convex lens are held separately in water. What changes, if any, do you expect in the focal length of either?

Long Answer Questions :

DIRECTIONS : *Give answer in 4 to 5 sentences.*

1. An object 5.0 cm in length is placed at a distance of 20 cm. in front of a convex mirror of radius of curvature 30 cm. Find the position of the image, its nature and size.

2. A truck uses a convex mirror as view finder whose radius of curvature is 2.0 m. A maruti car is coming behind the truck at a distance of 10 m. What will be the position of the image of the car and size of the image of the car when observed by the driver of the truck through the convex mirror ?

3. An object is placed 90 cm away from a concave mirror of focal length 30 cm. Find the position and the nature of the image formed.

4. Two thin converging lenses of focal lengths 0.15 m and 0.30 m are held in contact with each other. Calculate power and focal length of combination.

5. What is the focal length of a convex lens of focal length 30 cm. in contact with a concave lens of focal length 20 cm? Is the system a converging or diverging lens? Ignore thickness of the lenses.

6. Two thin lenses of focal lengths + 10 cm and – 5cm are kept in contact. What is the focal length and power of the combination?

7. If the wavelength of incident light on a (i) concave mirror and (ii) convex lens is increased, how will the focal length of each of these change?

8. Use the mirror formula to show that for an object lying between the pole and focus of a concave mirror, the image formed is always virtual in nature.

9. A concave lens has focal length of 20 cm. At what distance from the lens a 5 cm tall object be placed so that it forms an image at 15 cm from the lens? Also calculate the size of the image formed.

10. Prove that image in a plane mirror is as far behind as the object is in front of it.

11. Prove that the size of image formed by a plane mirror is equal to that of object.

2 EXERCISE

Text-Book Questions :

1. Define the principal focus of a concave mirror.
2. The radius of curvature of a spherical mirror is 20 cm. What is its focal length ?
3. Name a mirror that can give an erect and enlarged image of an object.
4. Why do we prefer a convex mirror as a rear-view mirror in vehicles?
5. Find the focal length of a convex mirror whose radius of curvature is 32 cm.
6. A concave mirror produces three times magnified real image of an object placed at 10 cm in front of it. Where is the image located ?
7. A ray of light travelling in air enters obliquely into water. Does the light ray bend towards the normal or away from the normal? Why?
8. Light enters from air to glass having refractive index 1.50. What is the speed of light in the glass ? The speed of light in vaccum is 3×10^8 m / sec.
9. Find out the medium having highest optical density. Also find the medium with lowest optical density.
10. You are given kerosene, turpentine and water. In which of these does the light travel fastest?
11. Define 1 dioptre of power of a lens.
12. A convex lens forms a real and inverted image of a needle at a distance of 50 cm from it. Where is the needle placed in front of the convex lens if the image is equal to the size of the object ? Also, find the power of the lens.
13. Find the power of a concave lens of focal length 2 m.

Text-Book Exercise :

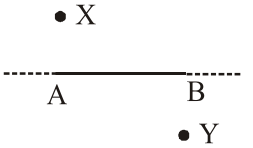
1. Which one of the following materials cannot be used to make a lens?
   (a) Water (b) Glass
   (c) Plastic (d) Clay
2. The image formed by a concave mirror is observed to be virtual, erect and larger than the object. Where should be the position of the object?
   (a) Between the principal focus and the centre of curvature
   (b) At the centre of curvature
   (c) Beyond the centre of curvature
   (d) Between the pole of the mirror and its principal focus.
3. Where should an object be placed in front of a convex lens to get a real image of the size of the object?
   (a) At the principal focus of the lens
   (b) At twice the focal length
   (c) At infinity
   (d) Between the optical centre of the lens and its principal focus
4. A spherical mirror and a thin spherical lens have each a focal length of –15 cm. The mirror and the lens are likely to be –
   (a) both concave
   (b) both convex
   (c) the mirror is concave and the lens is convex
   (d) the mirror is convex but the lens is concave.
5. No matter how far you stand from a mirror, your image appears erect. The mirror is likely to be
   (a) plane (b) concave
   (c) convex (d) either planer or convex
6. Which of the following lenses would you prefer to use while reading small letters found in a dictionary?
   (a) A convex lens of focal length 50 cm
   (b) A concave lens of focal length 50 cm.
   (c) A convex lens of focal length 5 cm
   (d) A concave lens of focal length 5 cm
7. We wish to obtain an erect image of an object, using a concave mirror of focal length 15 cm. What should be the range of distance of the object from the mirror? What is the nature of the image? Is the image larger or smaller than the object? Draw a ray diagram to show the image formation in this case.
8. Name the type of mirror used in the following situations.
   (a) Headlights of a car.
   (b) Side/rear-view mirror of a vehicle.
   (c) Solar furnace.
   (d) Support your answer with reason.
9. One-half of a convex lens is covered with a black paper. Will this lens produce a complete image of the object? Verify your answer experimentally. Explain your observations.
10. An object 5 cm in length is held 25 cm away from a converging lens of focal length 10 cm. Draw the ray diagram and find the position, size and the nature of the image formed.
11. A concave lens of focal length 15 cm forms an image 10 cm from the lens. How far is the object placed from the lens? Draw the ray diagram.
12. An object is placed at a distance of 10 cm from a convex mirror of focal length 15 cm. Find the position and nature of the image.
13. The magnification produced by a plane mirror is +1. What does this mean?
14. An object 5 cm in length is placed at a distance of 20 cm in front of a convex mirror of radius of curvature 30 cm. Find the position of the image, its nature and size.
15. An object of size 7 cm is placed at 27 cm in front of a concave mirror of focal length 18 cm. At what distance from the mirror should a screen be placed, so that a sharp focussed image can be otained ? Find the size and nature of the image.
16. Find the focal length of a lens of power –2D. What type of lens is this ?
17. A doctor has prescribed a corrective lens of power + 1.5D. Find the focal length of the lens. Is the prescribed lens diverging or converging?

Exemplar Questions :

1. Why does a light ray incident on a rectangular glass slab immersed in any medium emerges parallel to itself? Explain using a diagram.
2. A pencil when dipped in water in a glass tumbler appears to be bent at the interface of air and water. Will the pencil appear to be kerosene or turpentine. Support your answer with reason.
3. Sudha finds out that the sharp image of the window pane of her science laboratory is formed at a distance of 15 cm from the lens. She now tries to focus the building visible to her outside the window instead of the window pane without disturbing the lens. In which direction will she move the screen to obtain a sharp image of the building? What is the approximate focal length of this lens?
4. The image of a candle flame formed by a lens is obtained on a screen placed on the other side of the lens. If the image is three times the size of the flame and the distance between lens and image is 80 cm. at what distance should the candle be placed from the lens? What is the nature of the image at a distance of 80 cm and the lens?

HOTS Questions :

1. An object is placed at a distance of 15 cm from a convex mirror of focal length 30 cm. Find the position and the nature of the image.
2. An object 3 cm in height is placed 20cm from convex lens of focal length 12 cm. Find the nature, position and height of the image.
3. A concave lens has focal length of 15 cm. At what distance should the object from the lens be placed so that it forms an image at 10 cm from the lens ? Also, find the magnification produced by the lens.
4. A man standing in front of a spherical mirror, finds his image having a very small head, a fat body and legs of normal size. What types of mirrors are used in the small parts?
5. An image Y is formed of a point object X by a lens whose optic axis is AB as shown in figure. Draw a ray diagram to locate the lens and its focus. If the image Y of the object X is formed by a concave mirror (having the same optic axis AB) instead of lens, draw another ray diagram to locate the mirror and its focus. Write down the steps of construction of the ray diagrams.



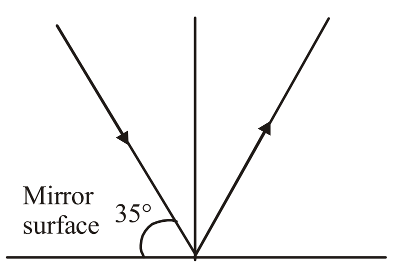
3 EXERCISE

Single Option Correct :

DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. Where should an object be placed in front of a convex lens to get a real image of the size of the object?
(a) At the principal focus of the lens
(b) At twice the focal length
(c) At infinity
(d) Between the optical centre of the lens and its principal focus.

2. Find the angle of incidence and angle of reflection from the diagram.



(a) 45°, 40° (b) 55°, 55°
(c) 60°, 60° (d) 30°, 30°

3. A spherical mirror and a thin spherical lens have each a focal length of –15 cm. The mirror and the lens are likely to be
(a) both concave.
(b) both convex.
(c) the mirror is concave and the lens is convex.
(d) the mirror is convex, but the lens is concave.

4. Which of the following lenses would you prefer to use while reading small letters found in a dictionary?
(a) A convex lens of focal length 50 cm.
(b) A concave lens of focal length 50 cm.
(c) A convex lens of focal length 5 cm.
(d) A concave lens of focal length 5 cm.

5. One light wave is incident upon a plate of refracting index μ. Incident angle i, for which refractive & reflective waves are mutually perpendicular will be
(a) $i = 45^\circ$ (b) $i = \sin^{-1}(\mu)$
(c) $i = \mathrm{cosec}^{-1}(\mu)$ (d) $i = \tan^{-1}(\mu)$

6. An object is situated at a distance of $f/2$ from a convex lens of focal length f. Distance of image will be –
(a) $+(f/2)$ (b) $+(f/3)$
(c) $+(f/4)$ (d) $-f$

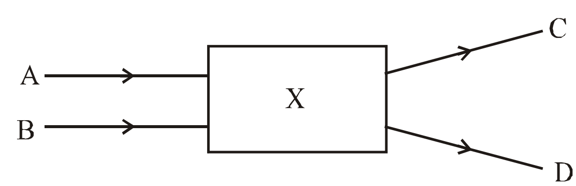
7. An object is placed 60 cm in front of a concave mirror. The real image formed by the mirror is located 30 cm in front of the mirror. What is the object's magnification?
(a) + 2 (b) –2
(c) + 0.5 (d) –0.5

8. Two plane mirrors are set at right angle and a flower is placed in between the mirrors. The number of images of the flower which will be seen is
(a) One (b) Two
(c) Three (d) Four

9. A man is 6.0 ft tall. What is the smallest size plane mirror he can use to see his entire image
(a) 3.0 ft (b) 6.0 ft
(c) 12 ft (d) 24 ft

10. An object is placed 60 cm in front of a convex mirror. The virtual image formed by the mirror is located 30 cm behind the mirror. What is the object's magnification
(a) + 2 (b) –2
(c) + 0.5 (d) – 0.5

11. Light rays A and B fall on optical component X and come out as C and D.



The optical component is a
(a) concave lens (b) convex lens
(c) convex mirror (d) prism

12. An object is placed 20.0 cm in front of a concave mirror whose focal length is 25.0 cm. What is the magnification of the object?
(a) + 5.0 (b) – 5.0
(c) + 0.20 (d) – 0.20

13. An object is placed at the radius of curvature of a concave spherical mirror. The image formed by the mirror is
(a) located at the focal point of the mirror.
(b) located between the focal point and the radius of curvature of the mirror.
(c) located at the center of curvature of the mirror.
(d) located out beyond the center of curvature of the mirror.

14. If the refractive indices for water and diamond relative to air are 1.33 and 2.4 respectively, then the refractive index of diamond relative to water is –
(a) .55 (b) 1.80
(c) 3.19 (d) None of these

15. There is an equiconvex lens of focal length of 20cm. If the lens is cut into two equal parts perpendicular to the principle axis, the focal lengths of each part will be
(a) 20 cm (b) 10 cm
(c) 40 cm (d) 15 cm

16. An object is placed 20.0 cm in front of a concave mirror whose focal length is 25.0 cm. Where is the image located?
(a) 1.0×10^2 cm in front of the mirror
(b) 1.0×10^2 cm behind the mirror
(c) 5.0×10^1 cm in front of the mirror
(d) 5.0×10^1 cm behind the mirror

17. Which statement best describes the property of light waves illustrated in the diagram below?

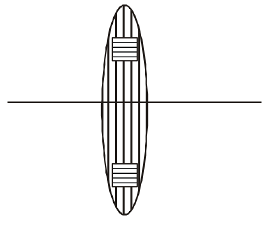
(a) Some materials absorb light waves.
(b) Some materials reflect light waves.
(c) Light waves are refracted by some materials.
(d) Light waves are emitted by some materials.

18. Light waves
(a) Require air or another gas to travel through
(b) Require an electric field to travel through
(c) Require a magnetic field to travel through
(d) Can travel through perfect vacuum

19. An object is placed 40.0 cm in front of a convex mirror. The image appears 15 cm behind the mirror. What is the focal length of the mirror?
(a) + 24 cm (b) + 11 cm
(c) – 11 cm (d) – 24 cm

20. Morning sun is not so hot as the mid day sun because
(a) Sun is cooler in the morning
(b) Heat rays travel slowly is the morning
(c) It is God gift
(d) The sun's rays travel a longer distance through atmosphere in the morning

21. The layered lens shown below is made of two different transparent materials.



A point object is placed on its axis. The object will form
(a) one image (b) infinite images
(c) no image (d) two images

22. An object is placed in front of a concave mirror of focal length 50.0 cm and a real image is formed 75 cm in front of the mirror. How far is the object from the mirror
(a) 25 cm (b) 30 cm
(c) 150 cm (d) –150 cm

23. A number of images of a candle flame can be seen in a thick mirror. The brightest image is
(a) Fourth (b) Second
(c) Last (d) First

24. A ray from air enters water, then through a thick layer of glass placed below water. After passing through glass, it again comes out in air medium. Then final emergent ray will
(a) Bend towards the normal
(b) Bend away from the normal
(c) Suffer lateral displacement
(d) Have the same path as if it had not passed through glass and water.

25. A concave spherical mirror has a radius of curvature of 100 cm. What is its focal length
(a) 50 cm (b) 100 cm
(c) 200 cm (d) 300 cm

26. Light is incident on an air-water interface at an angle of 25° to the normal. What angle does the refracted ray make with the normal
(a) 19° (b) 34°
(c) 25° (d) 90°

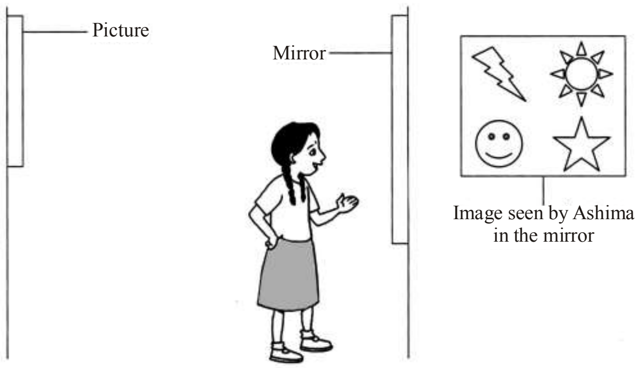
27. An object is placed 10.0 cm from a diverging lens which forms an image 6.5 cm from the lens. What is the focal length of the lens? Include the sign.
(a) + 3.9 cm (b) – 16.5 cm
(c) – 21.2 cm (d) – 18.6 cm

28. Under what conditions does a diverging lens form a virtual image of a real object
(a) Only if $u > f$.
(b) Only if $u < f$.
(c) Only if $u = f$
(d) A diverging lens always forms a virtual image of a real object.

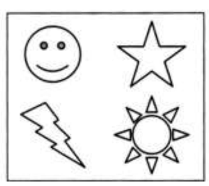
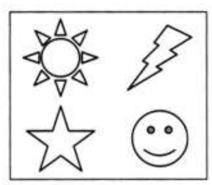
29. A lens produces a enlarged, virtual image. What kind of lens is it?
(a) converging
(b) diverging
(c) It could be either diverging or converging.
(d) None

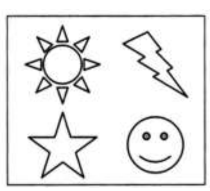
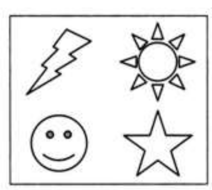
30. In an experiment to determine the focal length of a concave lens, a student obtained the image of a distant window on the screen. To determine the focal length of the lens, she/he should measure the distance between the
(a) lens and the screen only
(b) lens and the window only
(c) screen and the window only
(d) screen and the lens and also between the screen and the window

31. Ashima looks into the mirror and sees the reflection of the picture behind her.



Which of the following is the picture that is behind Ashima ?

(a)  (b) 

(c)  (d) 

32. On the basis of experiment 'to trace the path of a ray of light passing through a rectangular glass slab' four students arrived at the following interpretations :
I. Angle of incidence is greater than the angle of emergence.
II. Angle of emergence is less than the angle of refraction.
III. Emergent ray is parallel to the incident ray.
IV. Emergent ray is parallel to the refracted ray.
The correct interpretation is that of the student.
(a) I (b) II
(c) III (d) IV

33. Light waves
(a) are mechanical waves
(b) are electromagnetic waves
(c) travel with the same velocity in all media
(d) requires a material medium for their propagation

34. Virtual images of object of the same size are formed by
(a) a concave mirror (b) a convex mirror
(c) a plane mirror (d) all the above

35. Two plane inclined mirrors form 5 images by multiple reflection. The angle of inclination is
(a) 90° (b) 60°
(c) 45° (d) 30°

36. A bright × (cross) mark is made on a sheet of white paper. Over the white paper a rectangular glass-slab of thickness 3 cm is placed. On looking through, the image of the mark appears above the mark. It is below the upper surface of the slab by
(a) 2.5 cm (b) 1.5 cm
(c) 2 cm (d) 1.75 cm

37. The critical angle of a transparent medium denser than air
(a) increases with its refractive index
(b) decreases with its refractive index
(c) is independent of its refractive index
(d) None of these

38. Orange, blue and yellow are 3 of the colours formed by a prism. Their order according to increasing deviation is
(a) blue, orange, yellow (b) yellow, blue, orange
(c) blue, yellow, orange (d) orange, yellow, blue

39. Images formed by an object placed between two plane mirrors whose reflecting surfaces make an angle of 90° with one another lie on a
(a) Straight line (b) Zig-zag curve
(c) Circle (d) Ellipse

40. A diver in a swimming pool wants to signal his distress to a person lying on the edge of the pool by flashing his water-proof torch
(a) He must direct the beam of light vertically upwards
(b) He must direct the beam horizontally
(c) He must direct the beam at an angle to the vertical which is slightly lesser than the critical angle
(d) He must direct the beam at an angle to the vertical which is slightly greater than the critical angle

41. Two plane mirrors are inclined at an angle θ. A ray of light is incident on one mirror and is then reflected from the other mirror. Then the angle between the first ray and the final ray will be
(a) θ (b) 2θ
(c) between θ and 2θ (d) $> 2\theta$

42. A glass slab is placed in the path of a beam of convergent light, then the point of convergence of light
(a) moves towards the glass slab
(b) moves away from the glass slab
(c) remains at the same point
(d) undergoes a lateral shift

43. A real image is formed by a convex mirror when the object is placed at
(a) infinite
(b) between center of curvature and focus
(c) between focus and pole
(d) none of the above

44. A virtual image is formed by a concave mirror when the object is placed between
(a) infinity and center of curvature
(b) center of curvature and focus
(c) focus and the pole
(d) All of the above

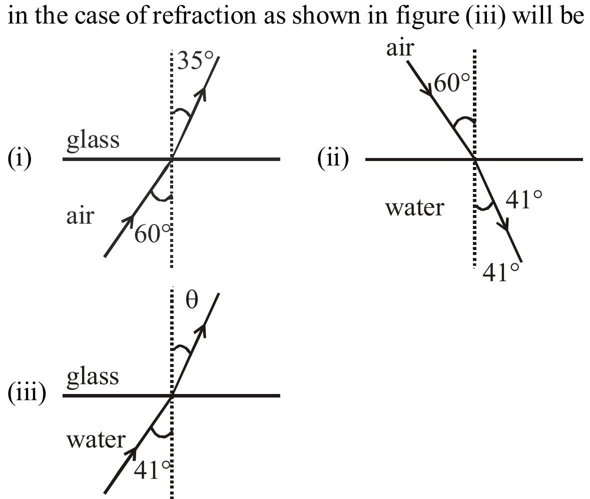
45. Which of the following are used in a Kaleidoscope
(a) plane mirrors (b) concave
(c) convex mirrors (d) all of the above

46. When a spherical convex lens made up of glass is immersed in water, its focal length
(a) decreases (b) does not change
(c) increases (d) none of the above

47. Out of the following
(a) pole (b) focus
(c) radius of curvature (d) principal axis
for a spherical mirror, the quantities that do not depend on whether the rays are paraxial or not, are
(a) a, b, c and d (b) only a, b and c
(c) only a, c and d (d) only a and d

48. A person standing at some distance from a mirror finds his image erect, virtual and of the same size. Then the mirror is possibly
(a) plane mirror
(b) concave mirror
(c) plane or concave mirror
(d) plane or concave or convex mirror

49. Refraction of light from air to glass and from air to water are shown in figure (i) and (ii) below. The value of the angle in the case of refraction as shown in figure (iii) will be :



(a) 30° (b) 35°
(c) 60° (d) none of the above

50. The focal length of a plane mirror is
(a) positive (b) negative
(c) zero (d) infinity

51. Rays from the sun converge at a point 15 cm in front of a concave mirror. Where should an object be placed so that size of its image is equal to the size of the object?
(a) 15 cm in front of the mirror
(b) 30 cm in front of the mirror
(c) between 15 cm and 30 cm in front of the mirror
(d) more than 30 cm in front of the mirror.

52. Under which of the following conditions a concave mirror can form an image larger than the actual object?
(a) When the object is kept at a distance equal to its radius of curvature
(b) When object is kept at a distance less than its focal length
(c) When object is placed between the focus and centre of curvature
(d) When object is kept at a distance greater than its radius of curvature

53. In case of a concave mirror, when the object is situated at the principal focus, the image formed is
(a) real and inverted (b) of infinite size
(c) lies at infinity (d) all of these

54. For an object at infinity, a concave mirror produces an image at its focus which is
(a) enlarged
(b) virtual
(c) erect
(d) real, inverted and diminished

55. An inverted image can be seen in a convex mirror,
(a) under no circumstances
(b) when the object is very far from the mirror
(c) when the object is at a distance equal to the radius of curvature of the mirror
(d) when the distance of the object from the mirror is equal to the focal length of the mirror

56. In order to get a diminished virtual image, the object can be placed anywhere in front of a
(a) concave mirror (b) plane mirror
(c) convex mirror (d) none of these

57. A full length image of a distant tall building can definitely be seen by using
(a) a concave mirror
(b) a convex mirror
(c) a plane mirror
(d) both concave as well as plane mirror

58. The concave mirrors are used in
(a) reflecting telescopes
(b) magic- lanterns
(c) cinema projectors
(d) all of these

59. Which of the following statements is true?
(a) A convex lens has 4 dioptre power having a focal length 0.25 m
(b) A convex lens has –4 dioptre power having a focal length 0.25 m
(c) A concave lens has 4 dipotre power having a focal length 0.25 m
(d) A concave lens has – 4 dioptre power having a focal length 0.25 m

60. A virtual, erect and magnified image of an object is to be produced with a concave mirror of focal length 12 cm. Which of the following object distance should be chosen for this purpose?
(a) 10 cm (b) 14 cm
(c) 18 cm (d) 24 cm

61. A 10 mm long awlpin is placed vertically in front of a concave mirror. A 5 mm long image of the awl pin is formed at 30 cm in front of the mirror. The focal length of this mirror is

(a) – 30 cm (b) – 20 cm
(c) – 40 cm (d) – 60 cm

62. The linear magnification for a mirror is the ratio of the size of the image to the size of the object, and is denoted by *m*. Then, m is equal to (symbols have their usual meanings):

(a) $\frac{f}{f-u}$ (b) $\frac{f-u}{f}$

(c) $\frac{f}{f+v}$ (d) $\frac{f+v}{f}$

63. In case of a real and inverted image, the magnification of a mirror is
(a) positive (b) negative
(c) zero (d) infinity

64. Magnification produced by a rear view mirror fitted in vehicles
(a) is less than one
(b) is more than one
(c) is equal to one
(d) can be more than or less than one depending upon the position of the object in front of it.

65. The ratio of the sine of angle of incidence to the sine of angle of refraction is called
(a) refractive index (b) optical density
(c) relative density (d) none of these

More than One Option Correct :

DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

1. Which of the following materials be used to make a lens?
(a) Water (b) Glass
(c) Plastic (d) Clay

2. The image formed by a concave mirror is observed to be virtual, erect and larger than the object. Where should not be the position of the object?
(a) Between the principal focus and the centre of curvature
(b) At the centre of curvature
(c) Beyond the centre of curvature
(d) Between the pole of the mirror and its principal focus.

3. No matter how far you stand from a mirror, your image appears erect. The mirror may be
(a) plane (b) concave
(c) convex (d) none of these

4. A lens behaves as a converging lens in air and diverging lens in water. The refractive index of the material of the lens can't be
(a) 1 (b) between 1 and 1.33
(c) 1.33 (d) greater than 1.33

5. On passing through a glass slab, red light doesn't suffer a change of
(a) wavelength (b) frequency
(c) amplitude (d) velocity

6. The focal length of a concave mirror doesn't depend upon
(a) The radius of curvature of the mirror
(b) The object distance from the mirror
(c) The image distance from the mirror
(d) The material of mirror

7. The radius of curvature of a plane mirror can't be
(a) zero (b) infinite
(c) negative (d) finite

8. Tick out the correct statements in the following
(a) Light travels with a speed greater than that of sound
(b) Light cannot travel through vacuum
(c) Light travels in a straight line
(d) Light has no weight

9. Choose the wrong statements regarding the image formation in a convex spherical mirror
(a) Images are always larger than the actual object
(b) Images are always smaller than the actual object
(c) Images are always of the same size as the actual object
(d) Images are always half of the actual object

10. The image formed by a convex spherical mirror is
(a) virtual (b) erect
(c) real (d) inverted

11. When light passes from air into glass it experiences a change of
(a) Speed (b) Wavelength and speed
(c) Frequency (d) amplitude

12. If a real object is placed inside the focal point of a concave mirror, the image is
(a) upright (b) real
(c) virtual (d) inverted

13. A person standing infront of a mirror finds his image smaller than himself and erect. This implies the mirror must not be
(a) plane (b) concave
(c) convex (d) None of the above

14. Choose the wrong statements regarding refraction of light
(a) The bending of light rays when they enter from one medium to another medium
(b) Splitting of white light into seven colours when it passes through the prism
(c) Bending of light round corners of obstacles and apertures
(d) Coming back of light from a bright smooth surface

15. A converging lens has a focal length of 15 cm. An object is placed 9.0 cm from the lens. Describe the image formed
(a) upright (b) inverted
(c) virtual (d) enlarged

16. Four students reported the following observation tables for the experiment, to trace the path of a ray of light passing through a glass slab for different angles of incidence. The observations, likely to be wrong are those of student.

i	r	e
30°	40°	30°
40°	50°	40°
50°	50°	50°

I

i	r	e
30°	20°	30°
40°	30°	40°
50°	40°	50°

II

i	r	e
30°	20°	40°
40°	30°	50°
50°	40°	60°

III

i	r	e
30°	20°	20°
40°	30°	30°
50°	40°	40°

IV

(a) I (b) II
(c) III (d) IV

17. The absolute refractive index of a medium depends on
(a) nature of the medium only
(b) wavelength of light only
(c) temperature of the medium only
(d) the angle of incidence

18. Mark the correct statements
(a) Refractive index decreases with increase in temperature
(b) Refractive index depends on the angle of incidence
(c) Foucault demonstrated experimentally that the speed of light in air is more than that in water
(d) Polarization of light was discovered by Malus

19. Mark the correct statements about a virtual image
(a) A virtual image can be photographed
(b) A virtual image can be seen
(c) A virtual image can be photographed by exposing a film at the location of the image
(d) A virtual image may be diminished or enlarged in size in comparison to an object.

20. Mark the correct statements
(a) A convex mirror produces an erect image
(b) A convex mirror always produces an erect image of an erect object
(c) A convex mirror always produces a diminished in size image
(d) A convex mirror is used as a shaving mirror

21. In vacuum the speed of light does not depend on
(a) Wavelength (b) Frequency
(c) Intensity (d) Speed of observer

22. When light passes from air to water which of the following changes
(a) Wavelength (b) Velocity
(c) Frequency (d) Colour

23. In case of reflection by a plane-mirror, which of the following statements are not correct
(a) It can never give real image
(b) It can never give inverted image
(c) It changes left into right
(d) It changes front into back

24. If two mirrors are inclined to each other at 90°, the image seen may be
(a) One (b) Two
(c) Three (d) Four

25. In case of three plane-mirrors meeting at a point to form a corner of a cube, if incident light suffers one reflection on each mirror
(a) The emergent ray is antiparallel to incident one
(b) The emergent ray is perpendicular to incident one
(c) The emergent ray is in phase with incident one
(d) The emergent ray is in opposite phase with incident one

Passage Based Questions :

DIRECTIONS : *Study the given passage(s) and answer the following questions.*

Passage-I

Inside a substance such as glass or water, light travels more slowly than it does in a vacuum. If c denotes the speed of light in a vacuum and v denotes its speed through some other substance, then $v = c/n$
where n is a constant called the index of refraction.
To good approximation, a substance's index of refraction does not depend on the wavelength of light. For instance, when red and blue light waves enter water, they both slow down by about the same amount. More precise measurements, however, reveal that n varies with wavelength. Table presents some indices of refraction of Custon glass, for different wavelengths of visible light. A nanometer (nm) is 10^{-9} meters. In a vacuum, light travels as $c = 3.0 \times 10^8$ m/s

Table : Indices of refraction of Custon glass

Approximately colour	Wavelength in vacuum (nm)	Indices n
yellow	580	1.5
yellow orange	600	1.498
orange	620	1.496
orange red	640	1.494

1. Inside Custon glass
(a) Orange light travels faster than yellow light
(b) Yellow light travels faster than orange light
(c) Orange and Yellow light travels equally fast
(d) We cannot determine which color of light travels faster

2. For blue-green of wavelength 520 nm, the index of refraction of Custon glass is probably closest to
(a) 1.49 (b) 1.50
(c) 1.51 (d) 1.52

3. Which of the following phenomena happens because n varies with wavelength
(a) A lens focuses light
(b) A prism breaks sunlight into different colors
(c) Total internal reflections ensures that light travels down a fiber optic cable
(d) Light rays entering a pond change direction at the pond's surface

Passage-II

A 5.0 cm tall object is placed perpendicular to the principal axis of a convex lens of focal length 20 cm. The distance of the object from the lens is 30 cm.

4. What is the distance of image from the pole of lens?
(a) $v = 60$ cm (b) $v = -60$ cm
(c) $v = 30$ cm (d) $v = -30$ cm

5. The size of the image formed by the lens is
(a) 1 twice the object size
(b) halved the object size
(c) one-fourth the object size
(d) one -third the object size

6. What is the power of the used lens?
(a) + 5 D (b) – 5 D
(c) + 0.5 D (d) – 0.5 D

Assertion & Reason :

DIRECTIONS : *Each of these questions contains an Assertion followed by Reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.
(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.
(c) If **Assertion** is **correct** but **Reason** is **incorrect**.
(d) If **Assertion** is **incorrect** but **Reason** is **correct**.

1. **Assertion :** A point object is placed at a distance of 26 cm from a convex mirror of focal length 26 cm. The image will not form at infinity.
Reason : For above given system the equation $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ gives $v = \infty$.

2. **Assertion :** When a concave mirror is held under water, its focal length will increase.
Reason : The focal length of a concave mirror is independent of the medium in which it is placed.

3. **Assertion :** A convex mirror is used as a driver's mirror.
Reason : Because convex mirror's field of view is large and images formed are virtual, erect and diminshed.

4. **Assertion :** Keeping a point object fixed, if a plane mirror is moved, the image will also move.
Reason : In case of a plane mirror, distance of object and Its image is equal from any point on the mirror.

5. **Assertion :** When the object moves with a velocity $\vec{v}$, its image in the plane mirror moves with a velocity of $-2\vec{v}$.
Reason : The minimum height of the mirror to be required to see the full image of man of height h is $\frac{h}{2}$.

6. **Assertion :** If both plane mirror and object are moved through a distance x, then the image moves through a distance $2x$.
Reason : When the object is fixed and plane mirror is moved through a distance x. Then the image is also moves through the distance $2x$.

7. **Assertion :** As the temperature of a medium increases the refractive index decreases.
Reason : When a ray travels from vacuum to a medium, then μ is known as absolute refractive index of the medium. ($\mu_{vacuum} = 1$).

8. **Assertion :** If a spherical mirror is dipped in water, its focal length remains unchanged.
Reason : A laser light is focused by a converging lens. There will be a significant chromatic aberration.

9. **Assertion :** A virtual image cannot be photographed.
Reason : Only real objects are photographed.

10. **Assertion :** The small object, to be seen in a microscope, is kept within the two foci of its objective.
Reason : In this case, the image formed by the objective is nearer to the eyepiece.

11. **Assertion :** Red light travels faster in glass than green light.
Reason : The refractive index of glass is less for red light than for green light.

12. **Assertion :** As light travels from one medium to another, the frequency of light does not change.
Reason : Because frequency is the characteristic of source.

Multiple Matching Questions :

DIRECTIONS : *Each question has four statements (A, B, C and D) given in Column I and 4 statements (p, q, r, s) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

1. A convex lens (f) forms an image on a screen Considering the object to be at the zero mark in a scale, match the following.

Column I	**Column II**
(A) Image	(p) Moves the image of infinite object further away
(B) Additional lens in contact	(q) Not unique as lens is moved between object and source.
(C) Reduction in refractive index	(r) Virtual for screen position at a distance $< 4f$ from the object.
(D) Slicing the lens to have one plane and another	(s) Object at d forms real image further convex surface nearer plano-convex lens.

	A	B	C	D
(a)	p, q	q	r	q,r
(b)	r	q	q,r,s	r,s
(c)	p,r	s	p	p, r
(d)	p	q, r	r	s

2. In the followoing columns, the positon of an object is given is column I and the nature of image formed in a concave mirror is given in column II.

Column I (Position of object)	**Column II (Nature of image)**
(A) At infinity	(p) Real
(B) Between infinity and centre of curvature	(q) Inverted
(C) At centre of curvature	(r) Diminished
(D) At focus	(s) Enlarged
	(t) Same size

	A	B	C	D
(a)	p, q	q	r, s	q, r
(b)	r, s	q,r	s, t	p,q,r,s
(c)	p, s	q	r,s,t	r
(d)	p, q, r	p, q, r	p, q, t	p, q

Integer/ Numeric Questions :

DIRECTIONS : *Following are integer based/Numeric based questions. Each question, when worked out will result in one integer or numeric value.*

1. A monochromatic ray of light strikes the surface of a transparent medium at an angle of incidence 60° and gets refracted into the medium at an angle of refraction 45°. What is the refractive index of the medium?
   [sin 60° = 0.866, sin 45° = 0.707]
2. A real image, 4/5 size of the object is formed 18 cm from a lens. Calculate the focal length of the lens.
3. 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, and (b) a concave lens of focal length 16 cm?
4. An object 50 cm tall is placed on the principal axis of a convex lens. Its 20 cm tall image is formed on the screen placed at a distance of 10 cm from the lens. Calculate the focal length of the lens.
5. An object 20 cm tall is placed on the principal axis of a convex lens. Its 30 cm tall image is formed on the screen placed at a distance of 10 cm from the lens. Calculate the focal length of the lens.
6. An object 30 cm tall is placed on the principal axis of a convex lens. Its 10 cm tall inverted image is formed on the screen placed at a distance of 15 cm from the lens. Calculate the focal length of the lens.
7. A convex lens has a focal length of 30 cm. Calculate at what distance should the object be placed from the lens so that in forms an image at 60 cm on the other side of the lens.
8. Where should an object be placed from a converging lens of focal length 20 cm, so as to obtain a real image of magnification 2?Find the magnification produced by the lens in this case.
9. A 5 cm tall object is placed on the principal axis of diverging lens of focal length 15 cm and at a distance of 10 cm from it. Find the nature, position and size of image.
10. An object 3.0 cm high is placed perpendicular to the principal axis of a concave lens of focal length 15.0 cm. The image is formed at a distance of 10.0 cm from the lens. Calculate
    (i) distance at which the object is placed and
    (ii) size and nature of the image formed.
11. An object 2.0 cm in size is placed 20.0 cm in front of a concave mirror of focal length 10.0 cm. Find the distance from the mirror at which a screen should be placed in order to obtain sharp image. What will be the size and nature of the image formed ?
12. A convex lens has a focal length of 25 cm. Calculate the distance of the object from the lens if the image is to be formed on the opposite side of the lens at a distance of 75 cm from the lens. What will be the nature of the image?
13. An object 3 cm high is placed at a distance of 9 cm in front of a concave mirror of focal length 18 cm. Find the position, nature and size of the image formed.
14. An object 4 cm high is placed at a distance of 20 cm in front of a convex lens of focal length 12 cm. Find the position, nature and size of the image formed.
15. Find the position, nature and size of the image of an object 3 cm high placed at a distance 6 cm from a concave mirror of focal length 12 cm.
16. Find the position of the object which when placed in front of a convex mirror produces a virtual image, which is half the size of the object.
17. Find the position of an object which when placed in front of a concave mirror of focal length 20 cm produces a virtual image, which is twice the size of the object.
18. An object is kept in front of a concave mirror of focal length 15 cm. The image formed is three times the size of object. Calculate two possible distances of the object from the mirror.
19. Monochromatic light of wavelength 589 nm is incident from air on a water surface. What are the wavelength, frequency and speed of (a) reflected (b) refracted light? (n of water = 1.33)
20. An object 10 cm long is placed at 15 cm away from a convex lens of focal length 10 cm. Find the position and size of image.
21. (a) State the relation between object distance, image distance and focal length of a spherical mirror.
    (b) A concave mirror of focal length 15 cm form an image of an object kept at a distance of 10 cm from the mirror. Find the position nature and size of the image formed by it.
    (c) Draw a ray diagram to show the image formed by a concave mirror when an object is placed between pole and focus of the mirror.

4 ADVANCED EXERCISE
BASED ON CONNECTING TOPICS

***DIRECTIONS (Qs. 1-10) :** This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. When viewed vertically a fish appears to be 4 meter below the surface of the lake. If the index of refraction of water is 1.33, then the true depth of the fish is
(a) 5.32 metres (b) 3.32 metres
(c) 4.32 metres (d) 6.32 metres

2. Light reflected from a boundary between an unknown substance and air is seen to become 100% polarized when the angle of incidence is 62.0°. What is the index of refraction of the unknown substance?
(a) 1.88 (b) 1.13
(c) 2.14 (d) 0.532

3. A convex lens of focal length 25 cm receives light from the sun. A diverging lens of focal length – 12 cm is placed 37 cm to the right of the converging lens. Where is the final image located relative to the diverging lens?
(a) 6 cm to the left (b) 25 cm to the left
(c) At infinity (d) 12 cm to the right

4. A camera lens focuses light from a 12.0 m tall building located 35.0 m away on film 50.0 mm behind the lens.
How tall is the image of the building on the film?
(a) 17.1 mm (b) 7.00 mm
(c) 2.50 cm (d) 1.25 mm

5. In comparison to the case when a ray of light travels from glass to air, the critical angle for total internal reflection of light when a ray of light travels from glass to water is
(a) greater (b) smaller
(c) same (d) nothing can be predicted

6. Material A has critical angle i_A, and material B has critical angle i_B ($i_B > i_A$). Then which of the following is true?
(i) Light can be totally internally reflected when it passes from B to A
(ii) Light can be totally internally reflected when it passes from A to B
(iii) Critical angle for total internal reflection is $i_B - i_A$
(iv) Critical angle between A and B is

$$\sin^{-1}\left(\frac{\sin i_A}{\sin i_B}\right)$$

(a) (i) and (iii) (b) (i) and (iv)
(c) (ii) and (iii) (d) (ii) and (iv)

7. On a rainy day, if there is an oil drop on tar road coloured rings are seen around this drop. This is due to
(a) total internal reflection of light
(b) polarisation
(c) diffraction pattern
(d) interference pattern produced due to oil film

8. If refractive index of glass is 1.50 and of water is 1.33, then critical angle is
(a) $\sin^{-1}(8/9)$ (b) $\sin^{-1}\left(\frac{2}{3}\right)$
(c) $\cos^{-1}\left(\frac{8}{9}\right)$ (d) None of these

9. Light waves can be polarised as they are
(a) transverse (b) of high frequency
(c) longitudinal (d) reflected

10. Diffraction and interference of light suggest
(a) nature of light is electro-magnetic
(b) wave nature
(c) nature is quantum
(d) nature of light is transverse

DIRECTIONS (Qs. 11-14) : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

11. A thin convavo convex lens has two surfaces of radii of curvature R and 2R. The material of the lens has a refractive index μ. When kept in air, the focal length of the lens
(a) will depend on the dircetion from which light is incident on it.
(b) will be the same, irrespective of the direction from which ligth is incident on it.
(c) will be equal to $\frac{R}{\mu - 1}$
(d) will be equal to $\frac{2R}{\mu - 1}$

12. A concave and a convex lens have the same focal length of 20 cm and are put in contact to form a lens combination. The combination is used to view an object of 5 cm length kept at 20 cm from the lens combination. As compared to the object, the image will not be
(a) magnified and inverted
(b) reduced and erect
(c) of the same size of the object and would be erect
(d) of the same size of the object, but would be inverted.

13. A lens of power + 2 diopter is placed in contact with a lens of power – 1 diopter. The combination will not behave like
(a) a convergent lens of focal length 50 cm
(b) a divergent lens of focal length 100 cm
(c) a convergent lens of focal length 100 cm
(d) a convergent lens of focal length 200 cm

14. Total internal reflection cannot take place only if
(a) light goes from optically rarer medium (smaller refractive index) to optically denser medium
(b) light goes from optically denser medium to rarer medium
(c) the refractive indices of the two media are close to different
(d) the refractive indices of the two media are widely different

DIRECTIONS (Qs. 15-17) : *Study the given paragraph(s) and answer the following questions.*

Passage

A convex lens of focal length 20 cm is placed in contact with a concave lens of focal length 60 cm.

15. The power of the convex lens is
(a) + 5 D (b) – 5D
(c) + 1.67 D (d) – 1.67 D

16. The power of the concave lens is
(a) + 5D (b) – 5D
(c) – 1.67 D (d) + 1.67 D

17. The focal length of the combination of lenses is
(a) + 20 cm (b) + 30 cm
(c) – 20 cm (d) – 30 cm

DIRECTIONS (Qs. 18-19) : *Each of these questions contains an Assertion followed by reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

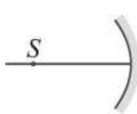
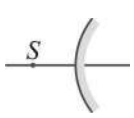
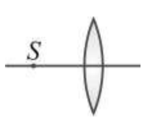
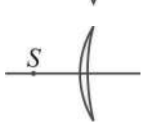
(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.
(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.
(c) If **Assertion** is **correct** but **Reason** is **incorrect**.
(d) If **Assertion** is **incorrect** but **Reason** is **correct**.

18. **Assertion :** Light rays retrace their path when their direction is reversed (Law of reversibility of light rays)
Reason : For the refraction light, water is denser than air, but for the refraction of sound, water is rarer than air.

19. **Assertion :** Speed of light in glass of $\mu = 1.5$ is 2×10^8 m/sec
Reason : According to dual theory, light has particle nature and wave nature simultaneously.

DIRECTIONS (Q. 20): *Following questions has four statements (A, B, C and D) given in Column I and 4 statements (p, q, r, s) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

20. An optical component and an object *S* placed along its optic axis are given in **Column I**. The distance between the object and the component can be visaed. The properties of images are given in **Column II**. Match all the properties of images from **Column II** with the appropriate components given in **Column I**.

Column I	**Column II**
(A) 	(p) Real image
(B) 	(q) Virtual image
(C) 	(r) Magnified image
(D) 	(s) Image at infinity

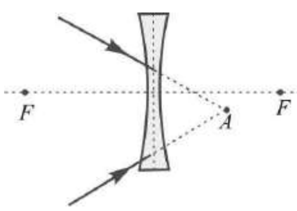
	A	B	C	D
(a)	p,q	q	r,s	q,r
(b)	p,q,r,s	q	p,q,r,s	p,q,r,s
(c)	p,s	q	r,s,t	r
(d)	p	q, r	r	s

DIRECTIONS (Qs. 21-25): : *Following are integer based/ Numeric based questions. Each question, when worked out will result in one integer or numeric value.*

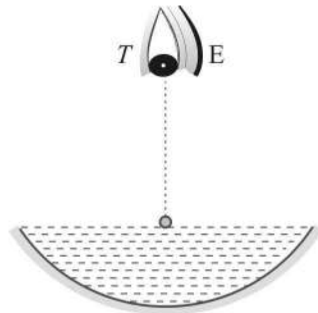
21. The focal length of lens of refractive index 1.5 in air is 30 cm. When it is immersed in water of refractive index 4/3, then find its focal length.

22. A glass sphere of radius 5 cm has a small bubble 2 cm from its centre. The bubble is viewed along a diameter of the sphere from the side on which it lies. How far from the surface will it appear. Refractive index of glass is 1.5.

23. A converging beam of rays is incident on a diverging lens. Having passed through the lens the rays intersect at a point 15 cm from the lens. If the lens is removed the point where the rays meet will move 5 cm closer to the mounting that holds the lens. Find focal length of the lens.



24. A concave mirror of radius 40 cm lies on a horizontal table and water is filled in it upto a height of 5.0 cm. A small dust particle P floats on the surface of water particle P lies vertically above the point of contact of the mirror with the table. Locate the image of the dust particle as seen from a point directly above it. The refractive index of water is 4/3.



25. A plane mirror of thickness 3 cm of material of refractive index $\frac{3}{2}$ is silvered on the back surface. A point object is placed at a distance of 9 cm from the unsilvered face of the mirror. Find the position of the brighest image.

SOLUTIONS

Brief Explanations of Selected Questions

1 EXERCISE

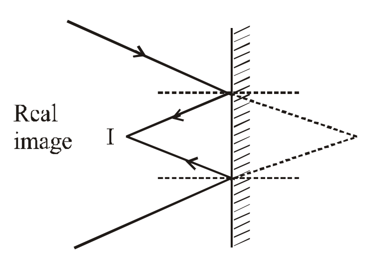
Fill in the Blanks :

1. positive, negative.
2. straight lines.
3. away from, towards
4. air-glass, glass-air, parallel
5. focal length
6. dioptre
7. equal
8. inwards, outwards.
9. concave
10. pole
11. front
12. principal axis
13. principal focus
14. concave
15. lens.
16. convergence or divergence
17. convex
18. 5/4

True / False :

1. True **2.** True **3.** True **4.** True **5.** True

6. False. plane mirror can form real image as shown.



7. True **8.** True **9.** True **10.** True **11.** True
12. False **13.** True **14.** False **15.** True **16.** False
17. True **18.** False **19.** False

Match the Following :

1. (A) $\rightarrow$ q; (B) $\rightarrow$ p; (C) $\rightarrow$ r; (D) $\rightarrow$ p
2. (A) $\rightarrow$ r; (B) $\rightarrow$ s; (C) $\rightarrow$ q; (D) $\rightarrow$ p

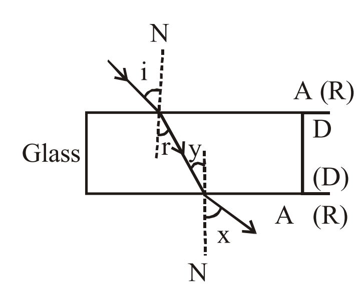
Very Short Answer Questions :

1. The bending of light when it passes from one medium to another is called refraction.
2. Focal length $= \dfrac{\text{Radius of curvature}}{2}$
3. Sending back of light in the same medium by a surface is called reflection of light.
4. 16 cm/sec. If an object moves towards the plane mirror with speed v, then image appears to move with speed 2 v.
5. (i) for real image $\rightarrow$ negative,
   (ii) for virtual image $\rightarrow$ positive
6. Convex
7. Benzene
8. Medium in which speed of light is less is known as optically denser medium and the medium in which speed of light is more is optically rarer medium.
9. They are reciprocal of each other i.e. ${}_1n_2 = \dfrac{1}{{}_2n_1}$
10. In medium B. (speed of light of is higher in a rarer medium).
11. Convex lens is known as converging lens and concave lens is known as diverging lens.
12. Either at infinity or beyond 2F.
13. No.
14. (i) Atmospheric refraction
    (ii) Total internal reflection.
15. Due to atmospheric refraction.

Short Answer Questions :

1. $${}_an_g = \frac{\sin i}{\sin r} \qquad ...(1)$$

$${}_gn_a = \frac{\sin y}{\sin x}$$



But $\angle y = \angle r$ [alt. $\angle$ s]
$\angle x = \angle i$ [$\angle$ of emergence $= \angle$ of incidence]

i.e. $${}_gn_a = \frac{\sin r}{\sin i}$$

Taking reciprocal, $$\frac{1}{{}_gn_a} = \frac{\sin i}{\sin r} \qquad ...(2)$$

From (1) & (2), $${}_an_g = \frac{1}{{}_gn_a}$$

2. When white light passes through a transparent medium like a glass prism it splits into seven colours. This phenomenon is called as dispersion of light.
The dispersion of light occurs due to different speeds of different colours when it passes through a glass prism.

3. Magnification, $m = -3$ (since image is real)
Object distance, $u = -10$ cm.
Image distance, $v = ?$
We know that magnification for the mirror

$$m = -\frac{v}{u} \quad \text{or} \quad -3 = -\frac{v}{-10} \quad \text{or} \quad v = -30 \text{ cm.}$$

4. Refractive index of glass $= \dfrac{\text{Speed of light in air}}{\text{Speed of light in glass}}$

or $\quad 1.5 = \dfrac{3 \times 10^8}{\text{Speed of light in glass}}$

or Speed of light in glass $= \dfrac{3 \times 10^8}{1.50} \text{ms}^{-1} = 2 \times 10^8 \text{ ms}^{-1}$

The speed of light in glass is 2×10^8 ms^{-1}.

5. Focal length, $f = -2$m (concave lens)

Power, $\quad P = \dfrac{1}{f\ (\text{in } m)} = \dfrac{1}{-2} = -0.5\, D$

6. The power of this lens has negative (–) sign, so it is a concave lens.

Power, $\quad P = \dfrac{1}{f\ (\text{in } m)}$

$\therefore \quad -2.0 = \dfrac{1}{f} \quad$ or $\quad f = \dfrac{1}{-2.0} m$

or $f = -0.50$ m
$\therefore$ Focal length, $f = -0.50$ m

7. Here, the focal length of the lens is given in cm. We should first convert the focal length into m.

Now, $\;10 \text{ cm} = \dfrac{10}{100} \text{m} = 0.1\text{m}$

So, focal length, $f = 0.1$m (a convex lens has positive focal length)

Now, $\quad P = \dfrac{1}{f\ (\text{in metres})}$

We get, $\quad P = \dfrac{1}{0.1} \quad$ or $\quad P = \dfrac{1 \times 10}{1}$

Thus, power $P = +10$ dioptre (or $+10\ D$)
The plus sign with the power indicates what it is a converging lens (or convex lens)

8. The image will be virtual and erect if $\mu < F$, the image will be smaller if $\mu > 2F$ and larger if $\mu < 2F$.

9. Let the distance between boy and miror by x.

Boy ——x—— Mirror ——x—— Image

i.e. $x + x = 20 \Rightarrow 2x = 20 \Rightarrow x = 10$ m

10. u = – 10 cm, f = – 20 cm

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} \Rightarrow \frac{1}{-20} = \frac{1}{v} + \frac{1}{-10}$$

$$\Rightarrow \frac{1}{v} = \frac{1}{10} - \frac{1}{20} = \frac{2-1}{20} = \frac{1}{20}$$

$\therefore$ v = 20 cm

$$m = \frac{-v}{u} = \frac{20}{10} = 2$$

m = 2
Image is formed 20cm behind the mirror i.e. virtual and erect and its m = 2. i.e. it is enlarged.

11. $\mu_r < \mu_g < \mu_y$.

12. 1 : 1

13. Given : Object distance $u = -12$ cm.
Magnification m = – 4.

We know that, $\quad m = -\dfrac{v}{u} = \dfrac{h'}{h}$

$\therefore \quad -4 = -\dfrac{v}{u} = -\dfrac{v}{(-12)} \quad \therefore \quad \upsilon = -48$ cm

So, image is formed at a distance of 48 cm on the same side of object.

14. Given : ${}_{air}n_{ice} = 1.31$, ${}_{air}n_{rock} = 1.54$

$${}_{ice}n_{rock} = \frac{{}_{air}n_{ice}}{{}_{air}n_{ice}} = \frac{1.54}{1.31} = 1.18.$$

15. $n_{ga} = 1.5$, $v_a = 3.0 \times 10^8\ ms^{-1}$, $v_g = ?$

$$n_{ga} = \frac{v_a}{v_g} \Rightarrow v_g = \frac{v_a}{n_{ga}} = \frac{3 \times 10^8}{1.5}$$

$\therefore$ Speed of light in glass $v_g = 2 \times 10^8$ ms^{-1}.

16. Convex lens increases its focal length, while the focal length of concave mirror remains same.

Long Answer Questions :

1. Radius of curvature of convex mirror, $R = 30$ cm.

$\therefore$ Focal length of convex mirror, $\quad f = \dfrac{R}{2} = \dfrac{30 \text{ cm}}{2} = 15\text{cm}.$

Now $h = 5$ cm, $u = -20$ cm, $v = ?$, $h' = ?$

Using the mirror formula $\dfrac{1}{f} = \dfrac{1}{v} + \dfrac{1}{u}$, we have

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{15} - \frac{1}{-20} = \frac{1}{15} + \frac{1}{20} = \frac{4+3}{60}$$

$$v = \frac{60}{7} = 8.6 \text{ cm.}$$

Thus, image is formed at a distance of 8.6 cm behind the convex mirror. The image is virtual and erect.

$$m = \frac{h'}{h} = -\frac{v}{u}$$

$$\frac{h'}{5} = -\frac{8.6}{-20} \Rightarrow h' = \frac{8.6}{20} \times 5 = 2.15 \text{ cm.}$$

2. For convex mirror, we have given
$u = -10$ m, $R = 2.0$ m

So, $f = \dfrac{R}{2} = \dfrac{2.0\text{m}}{2} = 1.0\,\text{m}$

Using the mirror formula, $\dfrac{1}{u} + \dfrac{1}{v} = \dfrac{1}{f}$

We get $\dfrac{1}{v} = \dfrac{1}{f} - \dfrac{1}{u} = \dfrac{1}{1.0} + \dfrac{1}{10} = \dfrac{11}{10}$

or $v = \dfrac{10}{11} = 0.9\,\text{m}$

Thus, the car would appear at 0.9 m from the convex mirror. We know that $m = -\dfrac{v}{u} = \dfrac{-\frac{10}{11}}{-10} = \dfrac{1}{11}$

Thus, size of the image of the car will be $\dfrac{1}{11}$ times smaller the actual size of the car through the convex mirror.

3. According to cartesian sign convention,
$u = -90$ cm, $f = -30$ cm.

We have the formula $\dfrac{1}{v} + \dfrac{1}{u} = \dfrac{1}{f}$

$\therefore \quad \dfrac{1}{v} - \dfrac{1}{90} = -\dfrac{1}{30}$

or $\quad \dfrac{1}{v} = -\dfrac{1}{30} + \dfrac{1}{90} = \dfrac{-3+1}{90} = \dfrac{-2}{90}$

$\therefore \quad v = -45$ cm.

Negative sign means that a real image is formed 45 cm from the mirror on the same side as the object.

4. 10D, 0.1 **5.** 60 cm. **6.** –10 cm, –10 D

7. (i) Focal length of concave mirror remains same, since it is independent of the wavelength of light.
(ii) When wavelength is increased, refractive index of glass for the particular colour decreases. Since focal length depends on μ, the focal length increases.

8. Mirror formula is, $\dfrac{1}{f} = \dfrac{1}{v} + \dfrac{1}{u}$ where u, v and f are object distance, image distance and focal length.

$\dfrac{1}{v} = \dfrac{1}{f} - \dfrac{1}{u}$

Focal length and object distance are both *–ve* for concave mirror.
It is given $u < f$,

$\therefore \quad \dfrac{1}{v}$ becomes $\dfrac{-1}{f} + \dfrac{1}{u}$ and is positive.

v becoming +ve denotes a virtual image.

9. $f = -20$ cm, $h_0 = 5$ cm, $v = -15$ cm.

Using $\dfrac{1}{f} = \dfrac{1}{v} - \dfrac{1}{u}$ we get,

$\dfrac{1}{u} = \dfrac{1}{v} - \dfrac{1}{f} = \dfrac{1}{-15} - \dfrac{1}{(-20)}$

$\dfrac{1}{u} = \dfrac{-20+15}{300} = -\dfrac{5}{300}$

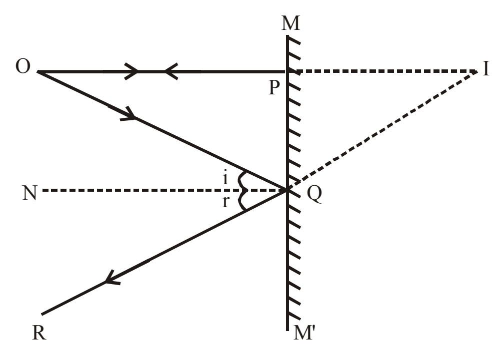
$u = -60$ cm.

Since $m = \dfrac{h_1}{h_0} = \dfrac{v}{u}$ we get,

$h_1 = \dfrac{v}{u}.h_0 = \dfrac{(-15)}{(-16)} \times 5 = \dfrac{5}{4}$

Image is enlarged and virtual.

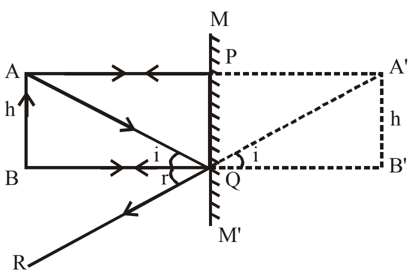
10. A point object O is placed in front of a plane mirror MM'. The ray OP falls normally on the mirror and it gets reflected back along the same path. Another ray from O fall at point Q and it gets reflected along the path QR in such a way that $\angle$i = $\angle$r. When these two reflected rays PO and QR are produced backward, a virtual image 'I' of object is formed behind the mirror.
In the fig. OP || QN



$\angle$i = $\angle$QOP (alternate angle)
$\angle$r = $\angle$PIQ (Corresponding angle)
But $\angle$i = $\angle$r (Law of Reflection)
$\therefore$ $\angle$QOP = $\angle$PIQ ______(1)
In Δ OPQ and Δ IPQ
$\angle$OPQ = $\angle$IPQ = 90°
$\angle$QOP = $\angle$PIQ [From (1)]
PQ = PQ (Common)
$\therefore$ ΔOPQ $\cong$ Δ IPQ (By ASA)
$\therefore$ OP = IP (CPCT)
i.e. Distance of the object from the mirror = Distance of image behind the mirror.

11. An extended object AB is placed in front of a plane mirror MM'. A light ray from A falls perpendicular on a mirror at P. So it comes back along the same path after reflection.

Another ray AQ (Q is a point of normal from B), falls on the mirror and after reflection it goes along the path QR. When these two reflected rays i.e. PA & QR are produced backward, they meet at a point A'. Similarly, the point B' is also obtained. It means A'B' is the image of AB. This image is virtual and erect which forms as far behind the mirror as the object is in front of it. i.e. AP = A'P.
BQ = B'Q



To prove : AB = A'B'.
Δ A'B'Q. = $\angle$A' Q B',= $\angle$r
(Vertically opposite angles)
$\angle$i = $\angle$r (laws of reflection)
$\therefore$ In Δ ABQ and Δ A'QB', $\angle$i = $\angle$A' Q B'
$\angle$ABQ = $\angle$A' B' Q = 90°
BQ = B' Q (becouse distance of image behind the mirror = distance object from the mirror)
$\therefore$ Δ ABQ $\cong$ ΔA'B'Q. (ASA).
$\therefore$ AB = A' B' (cpct) i.e. size of object = size of image.

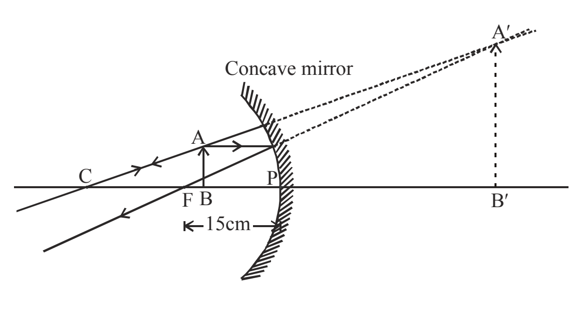
2 EXERCISE

Text-Book Questions :

1. The point on principal axis where beam of rays parallel to principal axis meet after reflection from the mirror is called principal focus.
2. R = 2f, R = 20 cm
   f = R/2 = 10 cm
3. Concave mirror can produce the erect and enlarge image of an object.
4. Because its aperture in large and it always forms virtual, erect and diminished image of distant objects.
5. R = + 32 cm
   f = R/2 = + 16 cm
6. M = – v/u (real)
   $$-3 = \frac{-v}{u}$$
   v = 3u, u = 10 cm (given)
   $\boxed{v = -30 \text{ cm}}$
7. It will bend towards the normal because the velocity of light decreases as it enters into water.
8. ${}^a\mu_g$ = 1.5 ; v = ? ; c = 3 × 10^8 m/sec
   $${}^a\mu_g = \frac{c}{v} \Rightarrow v = \frac{c}{{}^a\mu_g} = \frac{3\times10^8}{1.5} = 2\times10^8 \text{ m/sec}$$
9. Highest optical density is of Diamond (2.42).
   Lowest optical density is of Air (1.0003).
10. Light travels faster in water because the refractive index of water is least as compared to kerosene and turpentines.
11. When the focal length of a lens is one metre then the power of lens is called one dioptre.
12. v = + 50 cm ; m = 1 ; P = ? u = ?
    $$m = \frac{v}{u},\ \frac{1}{v} - \frac{1}{u} = \frac{1}{f},\ P = \frac{1}{f}$$
    $$-1 = \frac{50}{u},\ \frac{1}{50} + \frac{1}{50} = \frac{1}{f},\ P = \frac{1\times100}{25}$$
    $\boxed{u = -50 \text{ cm}}$, $\boxed{f = +25 \text{ cm}}$, $\boxed{P = 4 \text{ dioptre}}$
13. f = – 2 m
    $$P = \frac{1}{f} = \frac{1}{-2} = -0.5 \text{ dioptre}$$

Text-Book Exercise :

1. (d) Clay (Because clay is not a transparent material).
2. (d) Between the pole of the mirror and its principal focus
3. (b) At twice the focal length of lens.
4. (b) both concave. (Because concave lens and concave mirror have negative focal lengths.)
5. (d) Either plane or convex (Because plane mirror and a convex mirror always form a virtual and erect image.)
6. (c) A convex lens of focal length 5 cm. (Because its magnification is more than others as it is inversely proportional to the focal length $\left(m = \frac{v}{f} - 1\right)$).
7. The range of distance of the object is 0 to 15 cm in front of the mirror from the pole as the image in a concave mirror is erect when it is placed anywhere between the pole and the focus.
   (i) Nature of image : Virtual and erect
   (ii) Image is enlarged

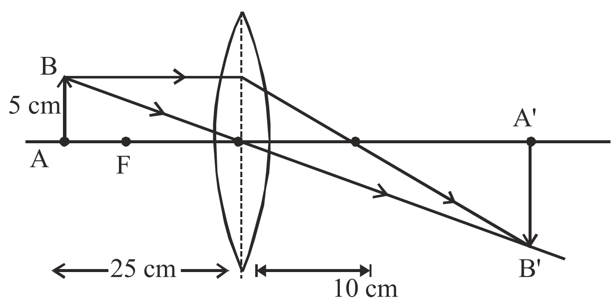


8. (a) Concave mirror because it provides a powerful parallel beams of light.
(b) Convex mirror because it provides a wide field of view.
(d) Concave mirror because it concentrates sunlight to produce heat.

9. Yes, this lens will produce a complete image of the object. The nature, size and location of the image will not change but the intensity of the image will become half.
Experiment : Let us take a convex lens. Cover one-half of it with a black paper. Put an object infront of it. Observe the image on the screen by adjusting it. It is observed that a complete image of the object is formed.

10. O = 5 cm ; u = – 25cm ; f = + 10 cm

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$$



$$\frac{1}{v}=\frac{1}{10}-\frac{1}{25}=\frac{5-2}{50}=\frac{3}{50}$$

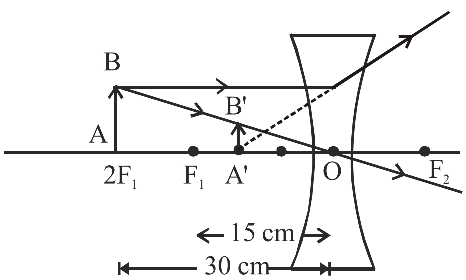
$$\boxed{v=\frac{50}{3}\text{cm}}\ m=\frac{v}{u}=\frac{I}{O},\ -\frac{50}{3\times 25}=\frac{I}{O}$$

$$\boxed{I=-3.33\,\text{cm}}$$

The image is real and inverted.

11. $$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$$

$$-\frac{1}{10}-\frac{1}{u}=-\frac{1}{15}$$



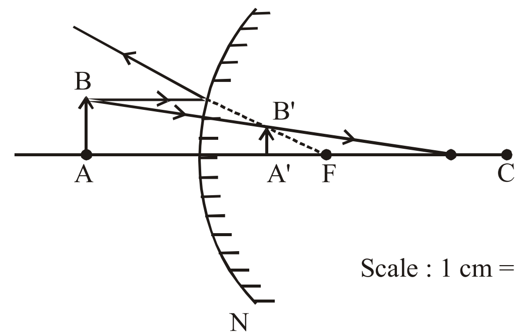
$$\frac{1}{u}=-\frac{1}{10}+\frac{1}{15}=\frac{-3+2}{30}=-\frac{1}{30}$$

$\boxed{u=-30\,\text{cm}}$ left side from the lens.

12. f = 15 cm ; u = – 10 cm ; v = ?

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$$

$$\frac{1}{v}=\frac{1}{15}+\frac{1}{10}=\frac{2+3}{30}=\frac{5}{30}=\frac{1}{6}$$



Scale : 1 cm = 5 cm.

Position of image = 1.2 cm
v = 1.2 × 5 = 6 cm

$\boxed{v=6\,\text{cm}}$ Image is formed on right side of mirror, so it is virtual and erect.

13. The magnification of a plane mirror is +1, it means that the image is of same size of the object. Also, it is erect and virtual.

14. O = 5 cm ; u = - 20 cm ; R = + 30 cm ;
f = R/2 = 15 cm ; u = ? ; I = ?

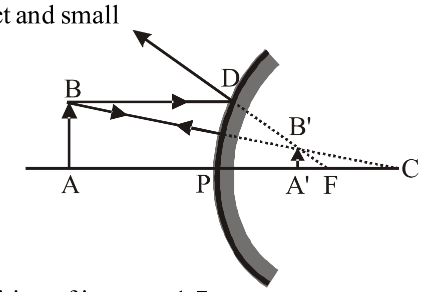
$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$$

$$\frac{1}{v}+\frac{1}{15}-\frac{1}{-20}=\frac{1}{15}+\frac{1}{20}=\frac{4+3}{60}=\frac{7}{60}$$

$\boxed{v=\frac{60}{7}\text{cm}}$ Image is formed on the right side of mirror.

$$m=-\frac{v}{u}=\frac{I}{o}$$

$\frac{-60}{-7\times 20}=\frac{I}{5}\Rightarrow\boxed{I=\frac{3}{7}\times 5=2.175\,\text{cm}}$ image is virtual, erect and small



Position of image = 1.7 cm
v = 1.7 × 5 = 8.5 cm
size of image = 0.4 cm
I = 0.4 × 5 = 2 cm

15. O = 7 cm ; u = – 27 cm ; f = – 18 cm ; v = ?, I = ?

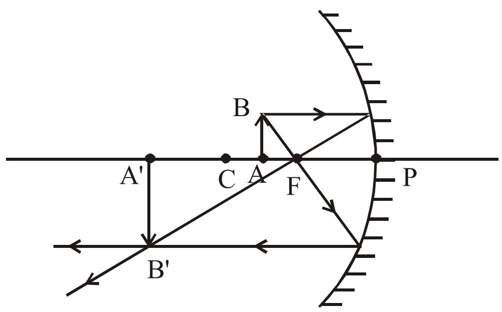
$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$$

$$-\frac{1}{27}+\frac{1}{v}=\frac{1}{-18}$$

$$\frac{1}{v}=\frac{1}{-18}+\frac{1}{27}=\frac{-3+2}{54}=\frac{-1}{54}$$

$\boxed{v=-54\,\text{cm}}$ Image is formed on left side of mirror.

$\boxed{\frac{I}{5}=\frac{-(-54)}{-27}=-10\text{ cm}}$ real, inverted and enlarged in size



Position of image = 6 cm
v = 6 × 9 = 54 cm
size of image = 1.1 cm
I = 1.1 × 9 = 10 cm

$$m=\frac{I}{O}=-\frac{v}{u}$$

16. $P=\frac{1}{f}$

$$-2=\frac{1}{f}$$

$\boxed{f=\frac{-1}{2}\text{m}=-50\,\text{cm}}$ The lens is concave lens.

17. $P=\frac{1}{f}$

$\boxed{f=\frac{1}{+1.5}\text{m}=0.67\text{m}}$ Lens is converging in nature.

Exemplar Questions :

2. No. Bending will be different in different liquids since velocity of light at the interface separating two media depends on the relative refractive index of the medium.

3. Sudha should move the screen towards the lens so as the obtain a clear image of the building. The approximate focal lenth of this lens will be 15 cm.

4. $m=-\frac{v}{u}=-3,$ using $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$ calculate u.

$u=-\frac{80}{3}$ cm, image is real and inverted. The lens is convex.

HOTS Questions :

1. u = – 15 cm, f = + 30 cm (for convex mirror, f is + ve)

The mirror formula is, $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ $\quad\therefore\ \frac{1}{v}=\frac{1}{f}-\frac{1}{u}$

Substituting the values of u and f in the above formula we have $\frac{1}{v}=\frac{1}{30}-\left(-\frac{1}{15}\right)=\frac{1}{30}+\frac{1}{15}=\frac{1+2}{30}=\frac{1}{10}$

$\therefore\ v$ = + 10 cm.

2. Since lens is convex, therefore f is positive.
Given u = – 20 cm, f = + 12 cm, h = 3 cm, v = ?, h' = ?
Since formula for a lens is

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f},\quad \frac{1}{v}-\frac{1}{-20}=\frac{1}{12}$$

$$\Rightarrow \frac{1}{v}+\frac{1}{20}=\frac{1}{12} \qquad \Rightarrow \frac{1}{v}=\frac{1}{12}-\frac{1}{20}$$

$$\Rightarrow \frac{1}{v}=\frac{5-3}{60}=\frac{1}{30} \qquad \Rightarrow v=30\text{ cm.}$$

Since 'v' is positive, the image is located on the other side of the lens.

$$m=\frac{v}{u}=\frac{+30}{-20}=-1.5$$

Since m is negative and greater than 1, the image is real, inverted and larger than the object.

$$m=\frac{h'}{h}\Rightarrow -1.5=\frac{h'}{3} \text{ or } h'=-4.5\text{ cm.}$$

Thus the image is 30 cm from the convex lens, located on the other side of the object. It is real inverted and 4.5 cm high.

3. A concave lens always forms a virtual, erect image on the same side of the object.
Image distance v = – 10 cm
Focal length f = – 15 cm,
Object distance u = ?

Since $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$ or $\frac{1}{u}=\frac{1}{v}-\frac{1}{f}$

$$\frac{1}{u}=\frac{1}{-10}-\frac{1}{(-15)}=-\frac{1}{10}+\frac{1}{15}$$

$$\frac{1}{u}=\frac{-3+2}{30}=\frac{1}{-30} \text{ or } u=-30\text{ cm.}$$

Thus, the object distance is 30 cm.

Magnification, $m=\frac{v}{u}$ or $m=\frac{-10\text{ cm}}{-30\text{ cm}}=\frac{1}{3}=+0.33$

4. A very small head → Convex mirror
A fat body → Concave mirror
Legs of normal size → Plane mirror

3 EXERCISE

Single Option Correct :

1. (b) **2.** (b) **3.** (a) **4.** (c)

5. (d) $\frac{\sin i}{\sin r} = \mu$. Angle between refractive & reflective waves

$= 180° - (i + r) = 90° \Rightarrow i + r = 90°$

$r = 90° - i$

$$\therefore \mu = \frac{\sin i}{\sin(90-i)} = \frac{\sin i}{\cos i} = \tan i \Rightarrow i = \tan^{-1}(\mu)$$

6. (d) For a spherical lens $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

For convex lens. u = – f/2 and f is + ve

$$\therefore \frac{1}{v} = \frac{1}{f} + \frac{1}{u} + \frac{1}{f} = + \frac{1}{f} - \frac{2}{f} \quad \therefore v = -f$$

7. (d) **8.** (c) **9.** (a) **10.** (c) **11.** (a) **12.** (a) **13.** (c)
14. (b) **15.** (c) **16.** (b) **17.** (c) **18.** (d) **19.** (d) **20.** (d)
21. (d) **22.** (d) **23.** (b) **24.** (c) **25.** (a) **26.** (a) **27.** (d)
28. (d) **29.** (a) **30.** (a) **31.** (b) **32.** (c) **33.** (b) **34.** (c)
35. (b) **36.** (c) **37.** (b) **38.** (d) **39.** (c) **40.** (c) **41.** (b)
42. (b) **43.** (d) **44.** (c) **45.** (a) **46.** (c) **47.** (c) **48.** (a)

49. (b) ${}_a\mu_g = \frac{\sin 60°}{\sin 35°}$ and ${}_a\mu_w = \frac{\sin 60°}{\sin 41°}$

$$\therefore \quad {}_a\mu_g = \frac{{}_a\mu_g}{{}_a\mu_w} = \frac{\sin 41°}{\sin\theta}$$

or $$\left(\frac{\sin 60°}{\sin 35°}\Big/\frac{\sin 60°}{\sin 41°}\right) = \frac{\sin 41°}{\sin\theta}$$

$$\therefore \quad \theta = 35°$$

50. (d) **51.** (b) **52.** (c) **53.** (d) **54.** (d) **56.** (a)
56. (c) **57.** (b) **58.** (d) **59.** (a) **60.** (a) **61.** (b)
62. (a) **63.** (b) **64.** (a) **65.** (a)

More Than One Option Correct :

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

Passage Based Questions :

1. (a) **2.** (c) **3.** (b)

4. Object size $h_0 = 5.0$ cm, $f = 20$ cm,
Object distance $u = -30$ cm

Since, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

(a) $\frac{1}{v} = \frac{1}{f} + \frac{1}{u}$

Then $\frac{1}{v} = \frac{1}{20} + \frac{1}{-30} = \frac{1}{60} \quad \therefore \; v = +60$ cm

Positive sign of v shows that image is formed at a distance of 60 cm to the right of the lens.
Therefore image is real and inverted.

5. (a) Since, $m = \frac{h'}{h} = \frac{v}{u}$

$$\therefore \quad h' = \frac{v \times h}{u} = \frac{60 \times 5}{-30} = -10 \text{ cm}$$

So, size of image is twice the size of object.

6. (a) Power $= \frac{1}{f} = \frac{1}{0.2m} = +5D$

Assertion & Reason :

1. (c) **2.** (d) **3.** (a) **4.** (d) **5.** (b)
6. (c) **7.** (b) **8.** (c)
9. (c) An image is a plane mirror is virtual and it can be photographed.
10. (c) Object is placed between F and $2F$ of objective lens.
11. (a) **12.** (a)

Multiple Matching Questions :

1. (c)
2. (d)

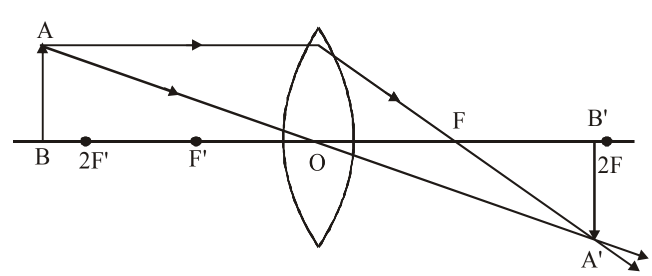
Integer/Numeric Questions :

1. Here, sine of angle of incidence ($\sin i$) = 0.866
and sine of angle of refraction ($\sin r$) = 0.707

Now, we have $$\mu = \frac{\sin i}{\sin r} = \frac{0.866}{0.707} = 1.22$$

Hence, the refractive index of the medium is 1.22.

2. Since the image is real and diminshed, the lens must be convex and the object must be placed beyond $2F$.



Given : $v = +18$ cm,

$\frac{h'}{h} = \frac{-4}{5}$, $f = ?$ [$\because m = \frac{h'}{h}$ is negative for real image]

We have, $m = \frac{h'}{h} = \frac{v}{u}$

$\therefore \frac{v}{u} = \frac{-4}{5}$ or $4u = -5v$ or $4u = -5 \times 18$ cm

$\therefore u = -22.5$ cm.

Now focal length is given by :

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} = \frac{1}{18} - \frac{1}{-22.5} = \frac{1}{18} + \frac{1}{22.5} = \frac{9}{90}$$

$\therefore f = 10$ cm.

3. (a) 7.5 cm
(b) 48 cm

4. $h_0 = 50$ cm, $h_1 = 20$ cm, $v = 10$ cm.

Using $m = \frac{h_1}{h_0} = \frac{v}{u}$, we get

With sign convention,

$$u = v\frac{h_0}{h_1} = 10 \times \frac{50}{(-20)} = -25 \text{ cm.}$$

Using $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ we get,

$$\frac{1}{f} = \frac{1}{10} - \frac{1}{-25} = \frac{25+10}{250}$$

$$f = \frac{250}{35} = 7.14 \text{ cm.}$$

5. $h_0 = 20$ cm, $h_1 = -30$ cm, $v = 10$ cm

$$m = \frac{h_1}{h_0} = \frac{(-30)}{20} = \frac{v}{u}$$

$$\therefore u = -\frac{10 \times 2}{3} = -\frac{20}{3} \text{ cm.}$$

Using $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ we get,

$$\frac{1}{f} = \frac{1}{10} - \frac{1}{\left(-\frac{20}{3}\right)} = \frac{1}{10} + \frac{3}{20} = \frac{5}{20} = \frac{1}{4}$$

$f = +4$ cm.

6. $h_0 = 30$ cm, $h_1 = -10$ cm, $v = 15$ cm

Using $m = \frac{h_1}{h_0} = \frac{v}{u}$, we get

$$\therefore u = v\frac{h_0}{h_1} = 15 \times \frac{30}{-10} = -45 \text{ cm.}$$

Using $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ we get,

$$\frac{1}{f} = \frac{1}{15} - \frac{1}{-45} = \frac{3+1}{45} = \frac{4}{45}$$

$$f = \frac{45}{4} = 11.25 \text{ cm.}$$

7. Given : For convex lens
$f = +30$ cm, $u = ?$, $v = +60$ cm, $m = ?$
From lens formula

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \qquad \therefore \frac{1}{30} = \frac{1}{60} - \frac{1}{u}$$

$$\Rightarrow \frac{1}{u} = \frac{1}{60} - \frac{1}{30} = \frac{1-2}{60}$$

$$\frac{1}{u} = -\frac{1}{60} \qquad \therefore u = -60 \text{ cm.}$$

So, the object should be placed at a distance of 60 cm to the left of the lens.
Magnification produced by lens,

$$m = \frac{h'}{h} = \frac{v}{u} = \frac{+60}{-60} = -1$$

Hence, real, inverted and same size image is obtained.

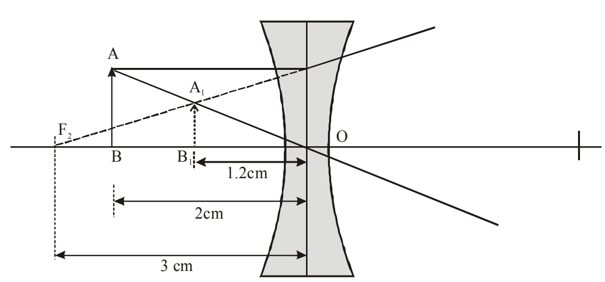
8. $f = +20$ cm, Since image is real, $m = -2$

Using, $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ and $m = \frac{v}{u}$

we get, $m = \frac{f}{f+u} \Rightarrow -2 = \frac{20}{20+u}$

$-40 - 2u = 20 \Rightarrow -2u = 60 \Rightarrow u = -30$ cm.

9. Let the scale be 5 cm = 1 cm
$\therefore$ Size of the object = 5 cm = 1 cm
$\therefore$ Distance of the object from the lens = 10 cm = 2 cm



$\therefore$ Focal length of the lens = 15 cm = 3 cm
On constructing the ray diagram, it is found
$\therefore$ size of the image = A_1B_1 = 0.6 cm = 0.6 × 5 cm = 3.0 cm
Distance of the image from lens = OB_1 = 1.2 cm = 1.2 × 5 cm = 6 cm
Nature : Image is virtual, erect and diminished

10. Here $h = 3.0$ cm, $f = -15$ cm, $v = -10.0$ cm

(i) From lens formula

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\therefore \frac{1}{u} = \frac{1}{v} - \frac{1}{f} = \frac{1}{-10} - \frac{1}{-15}$$

$$\frac{1}{u} = \frac{1}{15} - \frac{1}{10} = -\frac{1}{30} \quad \therefore \quad u = -30 \text{ cm.}$$

(ii) $m = \frac{h'}{h} = \frac{v}{u}$

$$\therefore h' \frac{v}{u} \times h \frac{-10}{-30} \times 3 = +1.0$$

From (i) and (ii), it is clear that image is formed on the same side of object placed at a distance of 30 cm and image is virtual, erect and of same size.

11. For a concave mirror

Given : $h = 2$ cm, u $= -20$ cm, $f = -10$ cm

$v = ?$ $h' = ?$

From mirror equation, we know that

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{-10} - \frac{1}{-20} = -\frac{1}{10} + \frac{1}{20}$$

$$= \frac{-2+1}{20} = \frac{-1}{20}$$

$\therefore \quad v = -20$ cm.

Also $m = \frac{h'}{h} = -\frac{v}{u} \Rightarrow \quad h' = -\frac{(-20) \times 2}{-20} = -2$

$\therefore$ Image size $h' = -2$ cm.

Position of image is 20 cm on the same side of object.

Nature of image : Real, inverted, same size ($h' = h$).

12. Focal length of convex lens, $f = +25$ cm image distance, $v = +75$ cm

From lens formula

$$\frac{1}{u} = \frac{1}{v} - \frac{1}{u}$$

$$\therefore \frac{1}{u} = \frac{1}{v} - \frac{1}{f} = \frac{1}{75} - \frac{1}{25} = -\frac{2}{75}$$

$$\Rightarrow u = -\frac{75}{2} = -37.5 \text{ cm}$$

Negative sign shows that image is real.

13. For a concave mirror,

$h = +3$ cm, $u = -9$ cm, $f = -18$ cm, $v = ?$, $h' = ?$

From mirror equation

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} \qquad \therefore \frac{1}{v} = \frac{1}{f} - \frac{1}{u}$$

$$= \frac{1}{-18} - \frac{1}{-9} = -\frac{1}{18} + \frac{1}{9} = \frac{1}{18} \quad \therefore v = +18 \text{ cm.}$$

i.e., image is formed behind the mirror at a distance of 18 cm. It is virtual.

Also, magnification $m = \frac{h'}{h} = -\frac{v}{u}$

$$\therefore \frac{h'}{+3} = -\frac{+18}{-9} = +2 \quad \therefore h' = +6 \text{ cm}$$

So, image is erect and twice the size of object.

14. Given : $h = +3.0$ cm, $u = -20$ cm, $f = +12$ cm, From lens formula

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \Rightarrow \frac{1}{12} = \frac{1}{\upsilon} - \frac{1}{-20}$$

$$\therefore \frac{1}{v} = \frac{1}{12} - \frac{1}{20} = \frac{5-3}{60} = \frac{2}{60} = \frac{1}{30}$$

$\therefore v = +30$ cm.

Also, $m = \frac{h'}{h} = \frac{v}{u}$

$$\Rightarrow \frac{h'}{3} = \frac{+30}{-20} = -\frac{3}{2} \quad \therefore h' = -\frac{9}{2} = -4.5 \text{ cm}$$

Therefore, Position of image : 30 cm to the right of the lens

Nature of image : real, inverted

Size of image : enlarge (4.5 cm).

15. $h_0 = 3$ cm, $u = -6$ cm, $f = -12$ cm

Mirror formula : $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$

$$\frac{1}{-12} = \frac{1}{v} + \frac{1}{-6}$$

$$\frac{1}{v} = \frac{-1}{12} + \frac{1}{6} = \frac{-1+2}{12} \; ; \; \frac{1}{v} = \frac{1}{12}$$

$\therefore \quad v = +12$ cm

$$m = \frac{h'}{h} = -\frac{v}{u}$$

$$h' = -\frac{v}{u} \times h = \frac{-12}{-6} \times 3 = +6$$

Position : image is formed behind the mirror at a distance of 12 cm.

Nature : virtual, erect, enlarged

Size of image : Twice the size of object.

16. Convex mirror, $m = 1/2$

Image is virtual, $\therefore \; m = +\frac{1}{2} \Rightarrow -\frac{v}{u} = \frac{1}{2}$

Therefore from $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$ we get

$$\frac{1}{f}=\frac{2}{u}+\frac{1}{u}=-\frac{1}{u} \quad \text{i.e., } u=-f$$

Object has to be at a distance equal to focal length.

17. $f = -20$ cm. Since image is virtual $m = +2$.

Using $\frac{1}{f}=\frac{1}{v}+\frac{1}{u}$ and $m=-\frac{v}{u}$

we get $m=\frac{f}{f-u}$ $\therefore$ $2=\frac{-20}{-20-u}$

$-40-2u=-20 \Rightarrow 2u=-20 \Rightarrow u=-10$ cm.

18. $f=-15$ cm, $h_1=3h_0$

For Real Image,

$$m=-\frac{v}{u}=-3 \therefore v=3u$$

using $\frac{1}{f}=\frac{1}{v}+\frac{1}{u}$, we get, $\frac{1}{-15}=\frac{1}{3u}+\frac{1}{u}$

$\Rightarrow u=-20$ cm.

For Virtual Image,

$$m=-\frac{v}{u}=+3 \Rightarrow v=-3u$$

using $\frac{1}{f}=\frac{1}{v}+\frac{1}{u}$

we get, $\frac{1}{-15}=\frac{1}{(-3u)}+\frac{1}{u} \Rightarrow u=-10$ cm.

The two possible positions are 10 cm and 20 cm in front of concave mirror.

19. $\lambda_{air} = 589\ nm = 589 \times 10^{-9}\ m$

Refractive index of water = $\mu = 1.33$

(a) Reflected light will have same wavelength, frequency and velocity.

$\therefore \lambda = 589\ nm$, $c = 3 \times 10^8$ ms^{-1}

$$f=\frac{c}{\lambda}=\frac{3\times10^8}{589\times10^{-9}}=5.09\times10^{-3+8+9}=5.09\times10^{14}\ Hz$$

(b) The frequency is same with refracted light. But, velocity and wavelength vary.

Since, $\mu=\frac{c}{v}$,

velocity in water $=\frac{3\times10^8}{1.33}=2.25\times10^8$ ms^{-1}

Since, $\mu=\frac{\lambda}{\lambda'}$,

wavelength in water is $\lambda'=\frac{\lambda}{\mu}=\frac{589\times10^{-9}}{1.33}=442$ nm.

20. $h_0=10$ cm, $u=-15$ cm, $f=+10$ cm

using $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$, we get,

$$\frac{1}{v}=\frac{1}{10}+\frac{1}{-15}=\frac{15-10}{150}=\frac{5}{150}$$

$$v=\frac{150}{5}=30 \text{ cm}$$

Image formed is real and is at a distance of 30 cm.

$$\frac{h_1}{h_0}=\frac{v}{u}= \therefore h_1=\frac{30}{-15}\times10=-20$$

Image is inverted since h_1 is $-ve$.

21. (a) The relation between object distance, image distance and focal length of a spherical mirror is given by

$$\frac{1}{f}=\frac{1}{v}+\frac{1}{u}$$

where f = Focal length of spherical mirror

v = Image distance, u = Object distance.

This relation is called mirror equation.

(b) For a concave mirror

Given : $f=-15$ cm, $u=-10$ cm, $v=?$, $m=?$

From mirror equation

$$\frac{1}{f}=\frac{1}{v}+\frac{1}{u}$$

$$\therefore \frac{1}{v}=\frac{1}{f}-\frac{1}{u}=\frac{1}{-15}-\frac{1}{-10}=\frac{-1}{15}+\frac{1}{10}$$

$$=\frac{-10+15}{150}=+\frac{5}{150}=+\frac{1}{30} \therefore v=+30 \text{ cm.}$$

Also, Magnification, $m=-\frac{v}{u}=-\frac{+30}{-10}=3.$

Hence, the image is formed at a distance of 30 cm behind the mirror.

Nature of image : Virtual, erect.

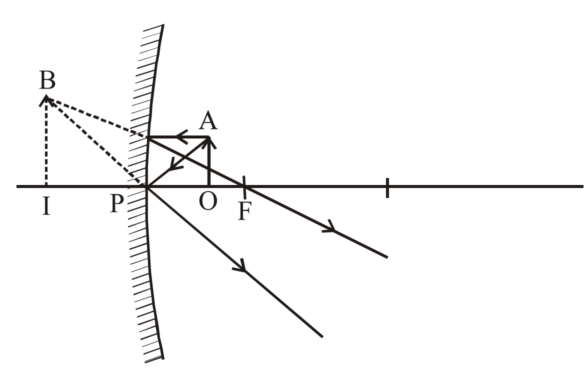
Size of image : Magnified, i.e., thrice the size of object.

(c) Position of object : Between pole and focus

Mirror : Concave.

Position of image : Behind the mirror.

Nature of image : Virtual, enlarged and erect.



4 ADVANCED EXERCISE
BASED ON CONNECTING TOPICS

1. (a) **2.** (a) **3.** (a) **4.** (a) **5.** (a)

6. (d) $i_B > i_A$ or $\sin^{-1}\left(\frac{1}{\mu_B}\right) > \sin^{-1}\left(\frac{1}{\mu_A}\right)$ or $\mu_A > \mu_B$

Hence medium A is denser and B is rarer.

Total internal Reflection : When the object is placed in a optically denser medium. and if the incident angle is greater than the critical angle then the ray of light gets reflected back to the originating medium.

For critical angle (α) from medium A to B, ${}_B\mu_A$

$${}_B\mu_A = \frac{1}{\sin\alpha} \text{ or } \sin\alpha = \frac{1}{{}_B\mu_A} = \frac{\mu_B}{\mu_A}$$

$$\Rightarrow \sin\alpha = \frac{1}{\sin i_B} \times \frac{\sin i_A}{1}$$

$$\Rightarrow \alpha = \sin^{-1}\left[\frac{\sin i_A}{\sin i_B}\right]$$

7. (d) The waves reflected from the top layer of oil interfere with the wave train reflected from the lower surface of thin oil film producing light and dark coloured pattern.

8. (a) The critical angle for total internal reflection from glass to water,

$$\sin i_c = \frac{\mu_{water}}{\mu_{glass}} = \frac{1.33}{1.55} = \frac{8}{9}.$$

$$i_c = \sin^{-1}\left(\frac{8}{9}\right)$$

9. (a) **10.** (b)

11. (b, d)

12. (a, b, d)

13. (a,b,d) $P = P_1 + P_2 = +2 - 1 = +1$ dioptre, lens behaves as convergent

$$F = \frac{1}{P} = \frac{1}{1} = 1\,\text{m} = 100\text{ cm}$$

14. (a, c, d)

15. (a) Power of convex lens $= \frac{100}{20} = +5D$

16. (c) Power of concave lens $= \frac{100}{60} = -1.67D$

17. (b) Power of combination $= P_1 + P_2 = +5 + (-1.67) = +3.33\,D$

$\therefore$ Focal length of combination $= \frac{100}{3.33} = +30$ cm

18. (b) **19.** (c)

20. (b)

21. $\because \frac{1}{f} = (\mu - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$

$$\therefore \frac{1}{30} = (1.5 - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

Refractive index of glass with respect to water

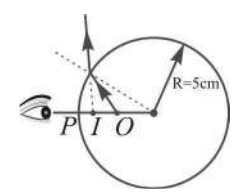
$$\mu_{wg} = \frac{\mu_{ag}}{\mu_{aw}} = \frac{1.5}{4} \times 3 = 1.125$$

$$\because \frac{1}{f'} = (\mu_{wg} - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

$$\text{or } \frac{1}{f'} = [1.125 - 1]\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

$$\text{or } \frac{f'}{30} = \frac{0.50}{0.125}$$

$\therefore f' = 120$ cm



22. For the object O,

$u = -(PO)$

$= -3$ cm

By refraction formula,

$$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}, \text{ we have}$$

$\mu_1 = 1.5$, $\mu_2 = 1$, and $R = -5$cm

$$\therefore \quad \frac{1}{v} - \frac{1.5}{-3} = \frac{1-1.5}{-5}$$

$$\Rightarrow \quad v = -2.5\text{ cm}$$

23. For concave lens, $u = +10$ cm (virtual object)

and $v = +15$ cm

We have $\frac{1}{+15} - \frac{1}{+10} = \frac{1}{f}$

$$\therefore \quad f = -30\text{ cm.}$$

24. For concave mirror, $u = -5$ cm, $f = -20$ m

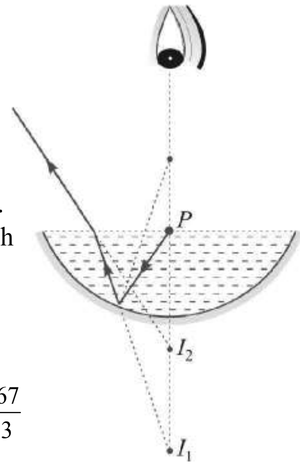
By mirror formula, $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$, we have

$$\frac{1}{v} + \frac{1}{-5} = \frac{1}{-20}$$

$$\therefore \quad v = +\frac{20}{3}\text{ cm}$$

Thus $OI' = \frac{20}{3}$ cm

$= 11.67$ cm



The distance $PI' = \frac{20}{3} + 5$

$= 11.67$ cm.

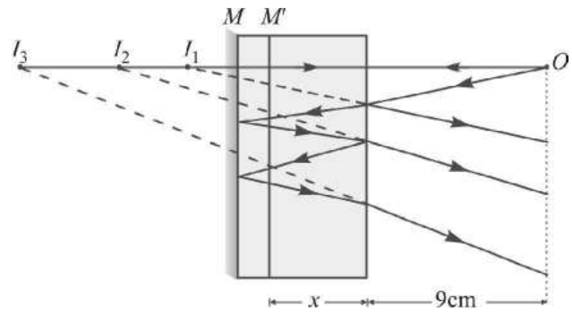
Now for the refraction through water surface, we have

$$\mu = \frac{RD}{AD}$$

$$\therefore \quad AD = \frac{RD}{\mu} = \frac{11.67}{4/3}$$

or $PI_2 = 8.75$ cm.

25. Because of multiple reflections and refractions, there will form infinite images; second of them will be brighest, which is formed by the reflection from the silvered face. Suppose M' is the apparent position of the mirror at a distance x from the unsilvered face of the mirror. Then



$$x = \frac{\text{real depth}}{\mu} = \frac{3}{3/2} = 2 \text{ cm}$$

The position of the object from $M' = 9 + 2 = 11$ cm.

By the definition, the position of the image

$= 11$ cm from M′

The position of the image from unsilvered face

$= 11 + 2 = 13$ cm

Chapter

2

HUMAN EYE AND COLOURFUL WORLD

INTRODUCTION

Light enables us to see things. But light alone cannot show us things visible. It does so with the help of 'eyes'. When eyes get defective, some visual aids are required. These aids can be in the form of spectacles. To see things bigger than their actual size, optical instruments are used. With the help of these instruments we can see distant objects like stars, sun, moon and other celestial objects very clearly. We can also see very small things very clearly with their aid.

Light makes our world colourful. When light passes through a prism, a very beautiful band of seven colours spectrum is obtained on a nearby screen. When sunlight falls on water droplets just after raining, a beautiful rainbow is observed.

This chapter is an attempt to provide a description of the eye, its defects and remedies, optical instruments and phenomena which makes our world colourful.

THE HUMAN EYE

The human eye is the organ which gives us the sense of sight, allowing us to learn more about the surrounding world than we do with any of the other four senses. We use our eyes in almost every activity we perform, whether reading, working, watching television, writing a letter, driving a car, and in countless other ways. Most people probably would agree that sight is the sense they value more than all the rest.

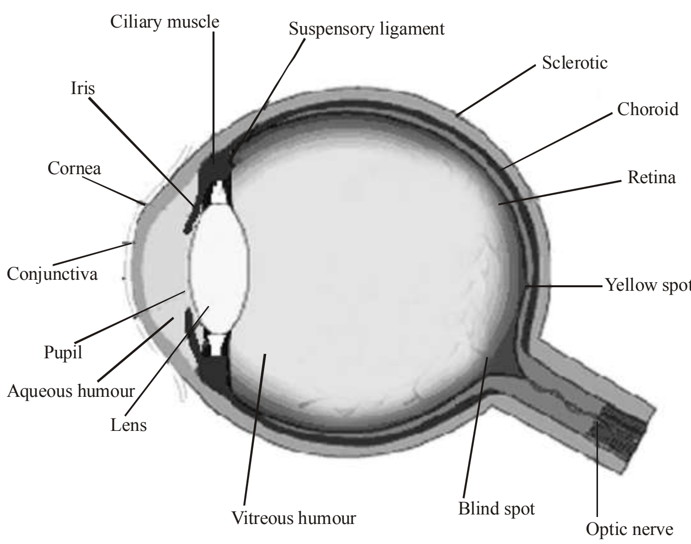


Fig. 2.1 Human eye

The eye allows us to see and interpret the shapes, colors, and dimensions of objects in the world by processing the light they reflect or emit. The eye is able to see in bright light or in dim light, but it cannot see objects when light is absent.
The diameter of human eye is about 2.3 cm.
The structure and function of its important parts are described below.

(i) **Retina :** It is a light sensitive screen inside the eye on which image is formed. It contains rods and cones.
(ii) **Cornea :** It is a thin membrane which covers the eye ball. It acts like a lens which refracts the light entering the eye.
(iii) **Aqueous humour :** It is fluid which fills the space between cornea and eye lens.
(iv) **Eye lens :** It is a Convex lens made of transparent and flexible jelly like material. Its curvature can be adjusted with the help of ciliary muscles.
(v) **Pupil :** It is a hole in the middle of iris through which light enters the eye. It appears black because light falling on it goes into the eye and does not come back.
(vi) **Ciliary muscles :** These are the muscles which are attached to eye lens and can modify the shape of eye lens which leads to the variation in focal lengths.
(vii) **Iris :** It controls the amount of light entering the eye by changing the size of pupil.
(viii) **Optical nerve :** These are the nerves which take the image to the brain in the form of electrical signals.

WORKING OF THE HUMAN EYE

Light waves from an object (such as a tree) enter the eye first through the cornea, which is the clear dome at the front of the eye. The light then progresses through the pupil, the circular opening in the center of the coloured iris. Next, the light passes through the crystalline lens, which is located immediately behind the iris and the pupil.

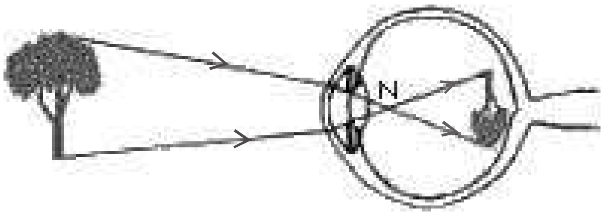


Fig. 2.2

Initially, the light waves are bent or converged first by the cornea, and then further by the crystalline lens, to a nodal point (N) located immediately behind the back surface of the lens. At that point, the image becomes reversed (turned backwards) and inverted (turned upside-down).

The light continues through the vitreous humor, the clear gel that makes up about 80% of the eye's volume, and then, ideally, back to a clear focus on the retina behind the vitreous. The small central area of the retina is the macula, which provides the best vision of any location in the retina. If the eye is considered to be a type of camera, the retina is equivalent to the film inside of the camera, registering the tiny photons of light which interact with it.
Within the layers of the retina, light impulses are changed into electrical signals and then sent through the optic nerve, along the visual pathway, to the cortex at the posterior or back of the brain. Here, the electrical signals are interpreted or "seen" by the brain as a visual image. When the light entering the eyes is bright enough, the pupils will constrict (get smaller), due to the pupillary light response.
Actually, then, we do not "see" with our eyes but, rather, with our brains. Our eyes merely are the beginnings of the visual process. You might have experienced that you are not able to see objects clearly for some time when you enter from bright light to a room with dim light. After sometime, however, you may be able to see things in the dim-lit room. The pupil of an eye acts like a variable aperture whose size can be varied with the help of the iris.
When the light is very bright, the iris contracts the pupil to allow less light to enter the eye. However, in dim light the iris expands the pupil to allow more light to enter the eye. Thus, the pupil opens completely through the relaxation of the iris.

POWER OF ACCOMMODATION

The ability of the eye lens to change its shape to focus near and distant objects clearly is called power of accommodation. The table shows how this is done.

Object	Ciliary muscles	Suspensory ligaments	Muscle tension on lens	Lens shape
Near	Contract	Slackened	Low	Thick
Distant	Relax	Stretched	High	Thin

When the eye is relaxed and the interior lens is the least rounded, the lens has its maximum focal length for distant viewing. As the muscle tension around the ring of muscle is increased and the supporting fibres are thereby loosened, the interior lens rounds out to its minimum focal length. *The minimum distance, at which objects can be seen most distinctly without strain, is called the* **least distance of distinct vision.** It is also called the near point(N.P.) of the eye. For a young adult with normal vision, the **near point is about 25 cm.** *The farthest point upto which the eye can see objects clearly is called the* **far point(F.P.)** of the eye. It is infinity for a normal eye. Thus a normal human eye can see objects clearly that are between 25 cm and infinity.

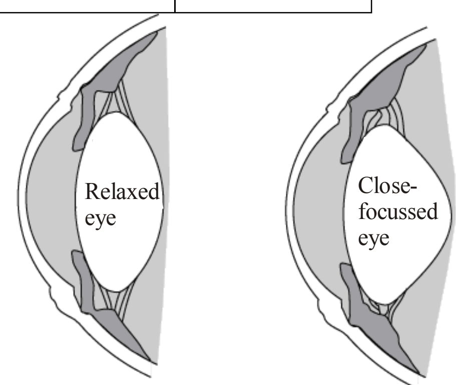


Fig.2.3

If an eye has the ability to assume a focal length of 1.80 cm (56 diopters) to view objects many miles away as well as the ability to assume a 1.68 cm focal length to view an object 0.25 meters away (60 diopters), then its Power of Accommodation would be measured as 4 diopters (60 diopters – 56 diopters).
The healthy eye of a young adult has a Power of Accommodation of approximately 4 diopters. As a person grows older, the Power of Accommodation typically decreases as a person becomes less able to view nearby objects. This failure to view nearby objects leads to the need for corrective lenses.
Many animals can see clearly both in water and on land. Some have extraordinary accommodation ranges, and others have developed other strategies. Cormorants and dippers can vary the refractive power of their lenses by 40-50 diopters, compared to about 16 diopters for an average adolescent human. The increased accommodation is due largely to highly developed sphincter muscles which vary the curvature of the front of the lens. Turtles and otters also have very strong sphincter muscles. Variations in lens geometries are used in various species of birds and fish.

Persistence of vision: *The image of any object seen persists on the retina for $1/10$ second even after the removal of the object. This continuance of sensation of eye is called persistence of vision. This property is used in cinematography.*

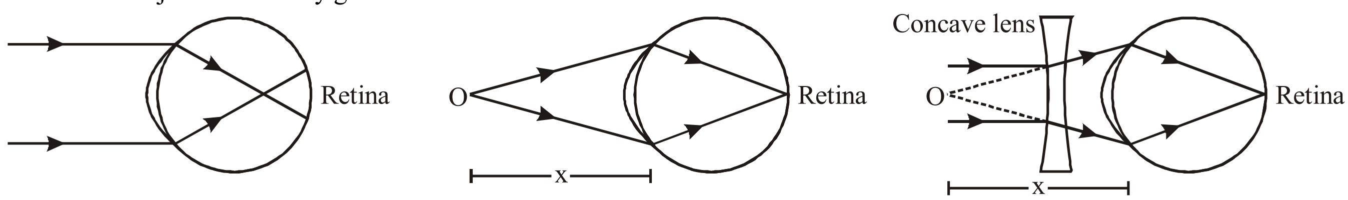
DEFECTS OF VISION AND THEIR CORRECTION

Myopia or Short-Sightedness

If the eyeball is too long or the lens too spherical, the image of distant objects is brought to a focus in front of the retina is out of focus again before the light strikes the retina. Nearby objects can be seen more easily.
A person with myopic eye can see nearby objects clearly but cannot see far off objects distinctly. Eyeglass with concave lens

corrects this problem by diverging the light rays before they enter the eye. Myopia most commonly develops in childhood or early teens (between 8 and 14). The risk of developing myopia is increased if there is a family history of it. There may also be a link between myopia and prolonged close-up work, such as reading or sitting close temporary short-sightedness, called pseudomyopia, can be caused by a number of diseases or certain drugs. For example, myopia may be the first sign of type-2 (non insulin-dependent) diabetes. Symptoms of pseudomyopia usually clear up if the underlying cause is treated to the television, although there is little scientific evidence for this.

Remeady: This defect can be corrected by using a concave lens of suitable focal length. A concave lens diverges the rays coming from the object so that they get focused at the retina.



(a) Myopic eye (b) Far point of a myopic eye (c) Corrected myopic eye

Fig. 2.4

Let a person can see an object at a maximum distance x m (i.e. far point is x). Thus, if the eye is to see a distant object clearly, the concave lens should form the virtual image of this distant object at a distance x. Thus, the required focal length of the lens is $f = -x$ and power of lens $P = \frac{1}{f} = -\frac{1}{x}$.

Knowledge ENHANCER

Let a nearsighted person can see upto a maximum distance x and wants to see upto a distance y then power of corrective lens

$$p = \frac{x-y}{xy}$$

Clearly from figure $u = -y;\quad v = -x;\quad f = ?$

$$\because \quad \frac{1}{f} = \frac{1}{v} - \frac{1}{u} = \frac{1}{-x} - \left(-\frac{1}{y}\right) = \frac{1}{y} - \frac{1}{x} = \frac{x-y}{xy}$$

$$\therefore \quad f = \frac{xy}{x-y} \text{ and } \quad P = \frac{x-y}{xy}$$

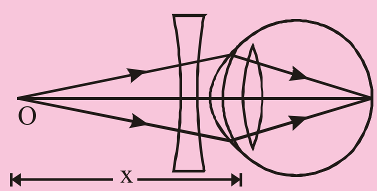


Fig. 2.5 (a)

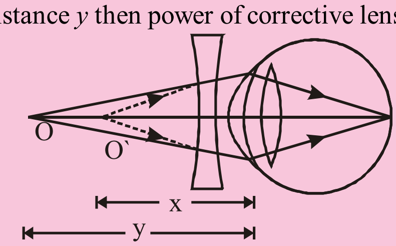


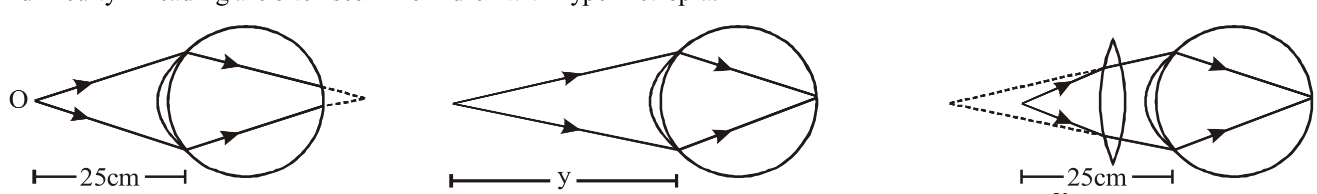
Fig. 2.5 (b)

Hypermetropia or Farsightedness

If the eyeball is too short or the lens too flat or inflexible, the light rays entering the eye–particularly those from nearby–objects will not be brought to a focs by the time they strike the retina.

A person with hypermetropic eye can see far off objects clearly but cannot see nearby objects clearly.

Remeady: Eyeglass with convex lens is used to rectify this problem. Squinting, eye rubbing, lack of interest in school, and difficulty in reading are often seen in children with hypermetropia.



(a) Hypermetropic eye (b) Near point of hypermetropic eye (c) Corrected hypermetropic eye

Fig. 2.6

Knowledge ENHANCER

Let the farsighted eye can see a minimum distance y (i.e. near point of the eye). If the eye is to see clearly an object at the least distance of distinct vision (i.e. at 25 cm), then the image of the object should form at a distance y.

$\therefore \quad u = -25 \text{ cm} \quad v = -y \quad f = ?$

By lens formula, $\frac{1}{f} = \frac{1}{v} - \frac{1}{u} = \frac{1}{-y} - \left(-\frac{1}{25 \text{ cm}}\right); \frac{1}{f} = \frac{1}{25 \text{ cm}} - \frac{1}{y}$

$\therefore \quad$ Power of lens, $P = \frac{1}{25 \text{ cm}} - \frac{1}{y}$

Presbyopia ("After 40" vision)

After age 40, and most noticeably after age 45, the human eye is affected by presbyopia, which results in greater difficulty in maintaining a clear focus at a near distance with an eye which sees clearly at a far away distance. This is due to a lessening of flexibility of the crystalline lens, as well as to a weakening of the ciliary muscles which control lens focusing, both attributable to the ageing process.

Person suffering from presbyopia require bifocal lenses. A common type of bi-focal lenses consists of both concave and convex lenses. The upper portion consists of a concave lens. It facilitates distant vision. The lower part is a convex lens. It facilitates near vision. These days, it is possible to correct the refractive defects with contact lenses or through surgical interventions.

Astigmatism

Astigmatism is the most common refractive problem responsible for blurry vision. Most of the eyeball's focusing power occurs along the front surface of the eye, involving the tear film and cornea (the clear 'window' along the front of the eyeball).

The ideal cornea has a perfectly the round surface.Any thing other than perfectly round contributes to abnormal connect.Curvature this is a stigmatism. Here's a good way to demonstrate the effects of astigmatism, look at your reflection in the curved surface of a round soup spoon and compare it with your reflection the cornea is the transparent leyer over the coloured part of the eye. It blends (refracts) light rays and helps focus the figures onto the retina in back of the eye so people can see. When the cornea is oblong shaped, it causes light rays to focus on two different points on the retina, instead of just one. As a result, people with significant astigmatism may have distorted or blurry vision.

Astigmatism may cause eye strain and also may be combined with nearsightedness or farsightedness.

Astigmatism can start in childhood or in adulthood.

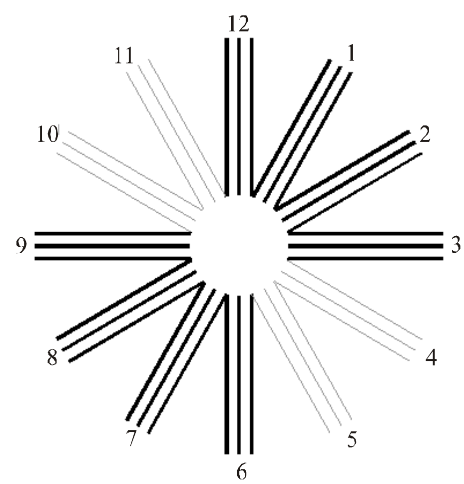


Fig. 2.7

Remeady: *Cylindrical lens is use to correct astigmatism.*

If the figure shown was constructed with all the radial lines of equal sharpness and contrast a person without astigmatism would see all these radial lines as perfectly sharp and with the same contrast. The diagram shown has been fudged to illustrate how it might appear to a person with astigmatism.

Cataracts

A cataract is a clouding of the lens in the eye. With people age, cataracts grow progressively darker and more dense, preventing light from easily passing through the lens. This results in vision loss.

Patients with cataracts have difficulty seeing in poorly lit environments. Many people also experience increased sensitivity to light and glare, double vision (or "ghost images"), and fading colors (blue may appear green; white may appear dull beige, etc.).

Most cataracts are highly treatable. Cataract surgery is one of the most common surgeries performed in the world with 95% of patients experiencing improved vision if there are no other eye conditions present. During surgery, the doctor removes the clouded lens, and, in most cases, replaces it with an artificial lens, called an intraocular lens (IOL). An IOL is a clear, plastic lens that requires no care and becomes a permanent part of your eye. Thick eyeglass lenses after surgery might not be needed because of the implanted lens.

Complicated cataracts cannot be extracted like normal cataracts because of potential complications such as other eye conditions, lack of vision in the other eye, or health concerns such as diabetes.

CHECK Point

Does short-sightedness (myopia) or long-sightedness (hypermetropia) imply necessarily that the eye has partially lost its ability of accommodation? If not, what might cause these defects of vision?

SOLUTION

A person with normal ability of accommodation may be myopic or hypermetropic due to deflective eye structure. When the eye ball from front to back gets too elongated the "myopic" defects occur, similarly when the eye ball from front to back gets too shortened the "hypermetropic" defects occur.

When the eye ball has normal length but the eyelens loses partially its ability of accommodation, the defect is called "presbyopia" and is corrected in the same manner as myopia or hypermetropia.

ILLUSTRATION : 2.1

A man who wears the corrective lenses of power +3D, has to hold a newspaper at 25 cm away to see the print clearly. How far away would the newspaper have to be, if he took off the corrective lenses and still, wanted a clear vision?

SOLUTION :

Here, $u = -25\text{cm}; p = +3\text{D}; v = ?$

The corrective lenses have the focal length $f = \frac{1}{P} = \frac{1}{3} m = \frac{100}{3}\text{cm}$

And the lens formula gives $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

$$\Rightarrow \frac{1}{v} - \frac{1}{-25} = \frac{1}{100/3} \Rightarrow \frac{1}{v} = \frac{3}{100} - \frac{1}{25} \Rightarrow v = -100\text{ cm}$$

which means that the corrective lenses used by man form the clear images at 100 cm of the objects placed at 25 cm, i.e., the near point of man is at 100 cm. Therefore, without wearing the corrective lenses the man must hold the newspaper at 100 cm for the clear vision.

ILLUSTRATION : 2.2

What should be the focal length of corrective lenses required by a person for reading a book, if his near point is at 90 cm?

SOLUTION :

The book is kept at the least distance of distance vision $D = 25$ cm, i.e., $u = -25$ cm and corrective lenses used form the clear images at 90 cm, which is the near point of person, i.e., $v = -90$ cm. Therefore, according to the lens formula, we have

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

$$\Rightarrow \frac{1}{-90} - \frac{1}{-25} = \frac{1}{f} \Rightarrow \frac{1}{f} = \frac{-5+18}{18 \times 25} \Rightarrow f = 34.6\text{ cm}$$

REFRACTION OF LIGHT THROUGH A PRISM

Prism is a transparent medium bounded by any number of surfaces in such a way that the surface on which light is incident and the surface from which light emerges are plane and non-parallel.

Consider a triangular glass prism. It has two triangular bases and three rectangular lateral surfaces. These surfaces are inclined to each other. The angle between its two lateral faces is called the angle of the prism A.

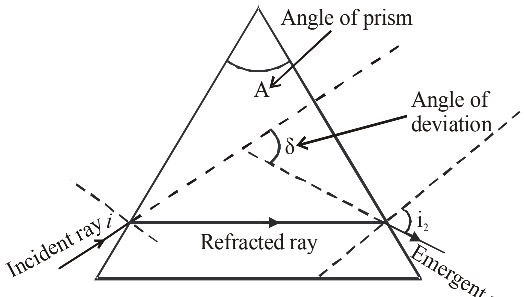


Fig. 2.8(a)

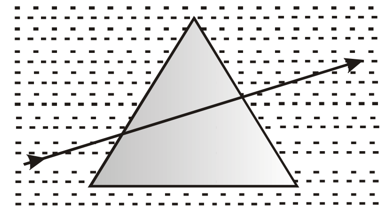


Fig. 2.8 (b) Light ray is not bent if glass is in fluid of the same index of refraction

In figure 2.8(a) you can see the incident ray, the refracted ray inside the prism and the emergent ray. You may note that a ray of light is entering from air to glass at the first surface. The light ray on refraction has bent towards the normal. At the second surface, the light ray has entered from glass to air. Hence it has bent away from the normal.

The peculiar shape of the prism makes the emergent ray bend at an angle to the direction of the incident ray. This angle is called **the angle of deviation.** It's not only the shape that matters but importantly difference of refractive index of prism material from surrounding makes ray to deviate, if glass prism is placed in a fluid with same refractive index as that of glass prism, ray will pass without deviation. Fig 2.8(b)

The angle between the emergent ray and incident ray is called **angle of deviation (δ).**

In quadrilateral, EGFN' the sum of its four angles should be 360°

$\therefore\ \angle AEN' + \angle AFN' + \angle A + \angle\alpha = 360°$

$\therefore\ 180° + \angle A + \angle\alpha = 360°$ or $\angle A + \angle\alpha = 180°$ ... (1)

In $\Delta EN'F$, $\angle r + \angle r' + \angle\alpha = 180°$ ... (2)

From eq. (1) and (2), $\angle A = \angle r + \angle r'$ ... (3)

In $\Delta\, GEF$, $\angle\delta$ = exterior angle

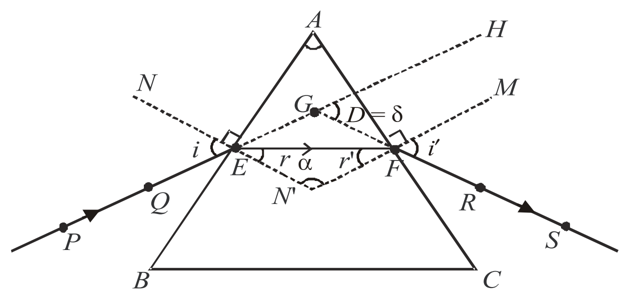


Fig. 2.9. Refraction of light through a triangular glass prism

$\therefore\ \angle\delta = (\angle i - \angle r) + (\angle i' - \angle r')$

$\angle\delta = (\angle i + \angle i') - (\angle r + \angle r')$ or $\delta = (i + i') - A$ ... (4)

For minimum deviation, angle of refraction (r) = angle of triangular prism (A)

ACTIVITY : To measure angle of incidence ∠*i*, angle of refraction ∠*r* , angle of emergence ∠*i*, angle of prism ∠A and angle of deviation ∠δ

- Fix a sheet of white paper on a drawing board using drawing pins.
- Place a glass prism on it in such a way that it rests on its triangular base. Trace the outline of the prism using a pencil.
- Draw a straight line *PE* inclined to one of the refracting surfaces, say *AB*, of the prism.
- Fix two pins, say at points *P* and *Q*, on the line *PE* as shown in Figure.
- Look for the images of the pins, fixed at *P* and *Q*, through the other face *AC*.
- Fix two more pins, at points *R* and *S*, such that the pins at *R* and *S* and the images of the pins at *P* and *Q* lie on the same straight line.
- Remove the pins and the glass prism.
- The line *PE* meets the boundary of the prism at point *E* (see Fig. 2.10). Similarly, join and produce the points *R* and *S*. Let these lines meet the boundary of the prism at *E* and *F*, respectively. Join *E* and *F*.
- Draw perpendiculars to the refracting surfaces *AB* and *AC* of the prism at points *E* and *F*, respectively.
- Mark the angle of incidence ($\angle i$), the angle of refraction ($\angle r$) and the angle of emergence ($\angle i'$) as shown in Fig. 2.10

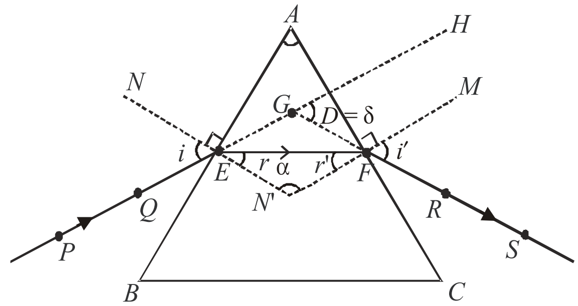


Fig. 2.10. Refraction of light through a triangular glass prism

PE – Incident ray, $\angle i$ – Angle of incidence, *EF* – Refracted ray, $\angle r$ – Angle of refraction, *FS* – Emergent ray,

$\angle i'$ – Angle of emergence, $\angle A$ – Angle of the prism, $\angle\delta$ – Angle of deviation.

CONNECTING TOPIC

ANGLE OF MINIMUM DEVIATION (δ_{MIN})

For each angle of incidence i, there is a corresponding angle of deviation δ. As we increase the angle of incidence from zero onwards, the corresponding angle of deviation first decreases, then takes a minimum value whereafter it starts increasing. Let us find out the magnitude of this minimum angle of deviation (δ_{min}).

Condition when δ will be minimum

δ will be minimum when $\angle i = \angle i'$ and $\angle r = \angle r'$

i.e., when angle of incidence equals to the angle of emergence.

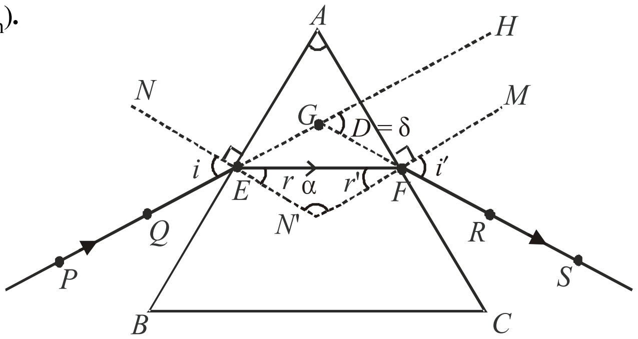


Fig. 2.11. Refraction of light through a triangular glass prism

$$\delta_{min} = 2i - A \quad \text{or} \quad i = \frac{1}{2}(A + \delta_{min})$$

$$\therefore \angle A = \angle r + \angle r' \Rightarrow A = 2r \quad \therefore \quad r = \frac{A}{2}$$

$$\text{Now, } \mu = \frac{\sin i}{\sin r} \Rightarrow \mu = \frac{\sin\left(\frac{A+\delta_{min}}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

For a small angled prism

If $\angle A$ is small and measured in radians, then $\sin\left(\frac{A+\delta_{min}}{2}\right) \approx \frac{A+\delta_{min}}{2}$ and $\sin\left(\frac{A}{2}\right) \approx \frac{A}{2}$

Putting these values in above-derived formula, we get

$$\mu = \frac{\frac{A+\delta_{min}}{2}}{\frac{A}{2}} \quad \text{or} \quad \mu = \frac{A+\delta_{min}}{A}$$

$$\mu A = A + \delta_{min} \qquad \therefore \ \delta_{min} = (\mu - 1)A$$

It is generally written as $\delta = (\mu - 1)A$

Knowledge ENHANCER

1. Condition of no emergence of a ray from a prism :

The light will not emerge out of a prism for all values of angle of incidence if at face AB, $i_1 = \max = 90°$, 12

at face AC, $r_2 > \theta_C$ ... (1)

Now from Snell's law, at face AB, we have

$1 \times \sin 90° = \mu \sin r_1$

i.e., $r_1 = \sin^{-1}(1/\mu)$ or $r_1 = \theta_C$ ... (2)

So from eq. (1) and (2), $r_1 + r_2 > 2\theta_C$ ... (3)

However, in a prism, $r_1 + r_2 = A$ ... (4)

So from eq. (3) and (4), $A > 2\theta_C$

or $\sin(A/2) > \sin\theta_C$ i.e., $\mu > [\text{cosec}\,(A/2)]$

i.e., A ray of light will not emerge out of a prism (whatever be the angle of incidence) if $A > 2\theta_C$, i.e., if $\mu > [\text{cosec}\,(A/2)]$

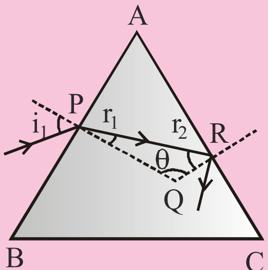


Fig. 2.12

2. Maximum deviation from a prism :

Deviation will be maximum when angle of incidence i_1 is maximum, i.e., $i_1 = 90°$, so eq. reduces to :

$$\delta_{max} = 90° + i_2 - A$$

However, when $i_1 = 90°$, $\quad 1 \sin 90° = \mu \sin r_1$

i.e., $r_1 = \sin^{-1}(1/\mu)$ or $r_1 = \theta_C$

and as in a prism $\qquad (r_1 + r_2) = A, \; r_2 = (A - \theta_C)$

So at surface AC, $\qquad \mu \sin r_2 = 1 \sin i_2 \;$ i.e., $\sin i_2 = \mu \sin (A - \theta_C)$

or $\qquad i_2 = \sin^{-1}[\mu \sin (A - \theta_C)]$

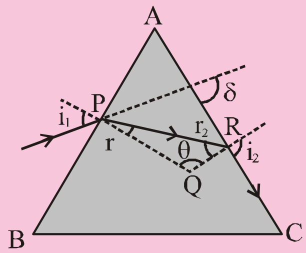


Fig. 2.13

ILLUSTRATION : 2.3

A ray of light falls normally on a refracting face of a prism of the refractive index $\mu = 1.5$ of its material. Find the angle of prism, if the ray just fails to emerge from the prism.

SOLUTION :

The angle of incidence of the ray of light at the refracting face AB is $i_1 = 0$ which implies that the angle of refraction at this face is $r_1 = 0$ and then, $r_1 + r_2 = A \;\Rightarrow\; r_2 = A$

At the second refracting face AC, the ray just fails to emerge and therefore,

$r_2 = A = i_c$

$$A = \sin^{-1}\left(\frac{1}{\mu}\right) = \sin^{-1}\left(\frac{1}{1.5}\right) = \sin^{-1}\left(\frac{2}{3}\right) = 42°$$

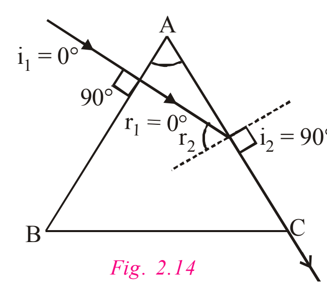


Fig. 2.14

ILLUSTRATION : 2.4

An equilateral prism is having the refractive index $\mu = 1.5$ of its material. Calculate the angle of emergence i_2 of the ray of light for the maximum deviation δ_{max}.

SOLUTION :

For the maximum deviation δ_{max} of the light ray, we have $i_1 = 90°$

$$r_1 = i_c = \sin^{-1}\left(\frac{1}{1.5}\right) = \sin^{-1}\frac{2}{3} = 42°$$

$\Rightarrow \quad r_2 = A - r_1 = 60° - 42° = 18°$ [As prism is equilateral $\therefore \angle A = 60°$]

Then, by the *Snell's Law,* we have

$$\sin i_2 = \mu \sin r_2 = 1.5 \times \sin 18° = 1.5 \times 18 \times \frac{\pi}{180} = 0.465 \;\Rightarrow\; i_2 = 28°$$

DISPERSION OF WHITE LIGHT BY A GLASS PRISM

The phenomenon of decomposition of the white light into seven component colours when passing through a prism or through a transparent object delimited by non parallel surfaces is called dispersion of light. A beam of light containing all the visible spectrum of the light is white, because the sum of all the colors generates the white color. Normally the light we use is white. It's the light containing all the colors mixed together. We can realize this fact when the beam of light passes through a glass prism: the light is decomposed in all the component colours, Violet, Indigo, Blue, Green, Yellow, Orange and Red, called as VIBGYOR. The band of the coloured components of a light beam is called its **spectrum**.

The phenomenon can be explained by thinking that light of different colours (different wavelengths) has different velocities while travelling in a medium: $\quad v_m = f\lambda_m$.

Hence, the change in velocity of light observed when the light passes from the air to the glass, depends on the wavelength.

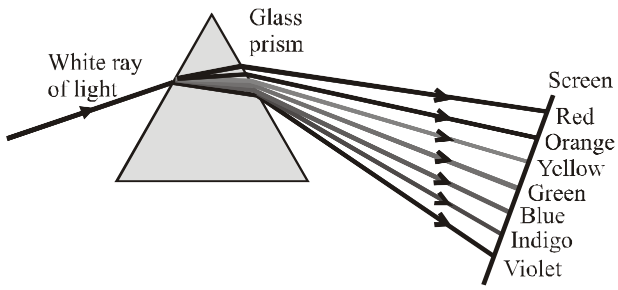


Fig. 2.15

By passing the interface air-glass, lower is the wavelength lower becomes the velocity of the light, so, for example, red light rays are faster than violet light rays.
This change in velocity coupled with the direction of the light beam to the air-glass interface explains the decomposition of a white light ray in the component colours while it is passing through a prism.
This phenomenon is known as "dispersion of light through a prism" and it is also responsible for rainbows during storms: as a matter of fact, each raindrop can be regarded as a little prism; when a light ray strikes a raindrop it is refracted and decomposed, spreading out all the visible colours ranging from red to violet.
Colours in the increasing order with respect to wavelength are as follow: *Violet* (*min.*), *Indigo, Blue, Green, Yellow, Orange, red* (*max.*)

NEWTON'S TWO PRISMS EXPERIMENT

Recombination of Different colours of spectrum to give white light

Newton took two prisms P_1 and P_2 of the same material and having the same refracting angle. He made white light pass through a slit and allowed it to fall on prism p_1(See Fig. 2.16). He obtained a spectrum (VIBGYOR) on the white screen. He removed the white screen and placed prism P_2 in an inverted position as shown in Figure. It was observed that the light coming out of the second prism P_2 was almost white.

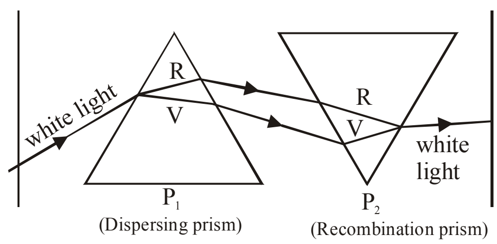


Fig. 2.16 Recombination of different colours forms white light

This experiment proved that the prism P_1 dispersed the white light into its constituent colours. Hence, this prism was called the **dispersing prism.** The second prism P_2 recombined the seven constituent colours to form white light. Hence, this prism was called the **recombination prism.** This experiment thus proved that

1. the prism by itself produces no colours.
2. the recombination of the seven constituent colours forms white light.

CONNECTING TOPIC

ANGLE OF DISPERSION

The angle between the rays of the extreme colours (i.e red and violet) in the refracted (dispersed) light is called the angle of dispersion θ.

That is, $\theta = \delta_V - \delta_R$

DISPERSIVE POWER (W)

Dispersive power of the medium of the material of prism is given by

$$\omega = \left(\frac{\text{angular dispersion}}{\text{deviation of mean ray (yellow)}}\right) = \frac{\theta}{\delta_Y}$$

For small angled prism $(A \le 10°)$ with light incident at small angle *i*.

$$\omega = \frac{\delta_V - \delta_R}{\delta_Y} = \frac{\mu_V - \mu_R}{\mu_Y - 1} \text{ [take } \mu_Y = \frac{\mu_V + \mu_R}{2} \text{ if value of } \mu_Y \text{ is not given in the problem.]}$$

μ_V, μ_R and μ_Y are R.I. of material for violet, red and yellow colours respectively.

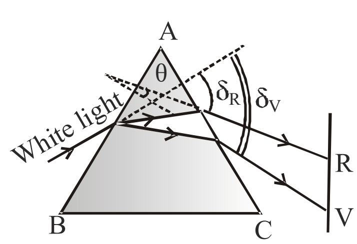


Fig. 2.17

CAUSE OF DISPERSION

The cause of dispersion is the dependence of the refractive index (μ) on wavelength of light which is given by

Cauchy's formula $\mu(\lambda) = a + \dfrac{b}{\lambda^2}$ (where *a* and *b* are positive constants)

The different colours of light corresponds of different refractive index of the prism. Hence, different colours have different velocities in the prism and hence get separated from one another.

Combination of Two Prisms

If two prisms of prism angles A and A' and refractive indices μ and μ' are placed together,

$$\delta = \delta_1 + \delta_2 = (\mu - 1)\,A + (\mu' - 1)\,A'$$

and $\theta = \theta_1 + \theta_2 = (\mu_V - \mu_R)\,A + (\mu'_V - \mu'_R)\,A'$

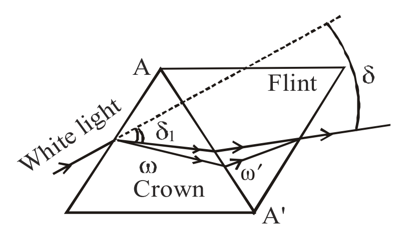
(a) For deviation without dispersion (Achromatic Prism)

$$\theta = 0, \quad i.e., \quad A' = -\frac{(\mu_V - \mu_R)}{(\mu'_V - \mu'_R)}A \qquad \text{............ (1)}$$

i.e., the two prisms must be placed with their prism angles in opposite directions so that condition given by eq. (1) may be satisfied. In this situation

$$\delta = (\mu - 1)\,A - (\mu' - 1)\frac{(\mu_V - \mu_R)}{(\mu'_V - \mu'_R)}A$$

i.e., $\delta = (\mu - 1)\,A\left[1 - \dfrac{(\mu_V - \mu_R)}{(\mu - 1)} \times \dfrac{(\mu' - 1)}{(\mu'_V - \mu'_R)}\right]$



Deviation without dispersion
Fig. 2.18 (a)

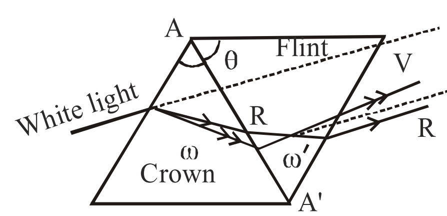
But as $\delta_1 = (\mu - 1)\,A, \quad \omega = \dfrac{(\mu_V - \mu_R)}{(\mu - 1)}A$ and $\omega' = \dfrac{(\mu'_V - \mu'_R)}{(\mu' - 1)}$

$$\delta = \delta_1[1 - (\omega/\omega')] \qquad \text{............ (2)}$$

Usually $\omega' > \omega$, so δ is in the same direction as produced by the first prism.

(b) For dispersion without deviation (Direct vision spectroscope)

$$\delta = 0 \quad \text{i.e.,} \quad A' = -\frac{(\mu - 1)}{(\mu' - 1)}A$$



Dispersion without deviation

Fig. 2.18 (b)

In this situation, $\theta = (\mu_V - \mu_R)A - (\mu'_V - \mu'_R) \times \dfrac{(\mu - 1)}{(\mu' - 1)}A$

i.e., $\theta = (\mu - 1)\,A\left[\dfrac{(\mu_V - \mu_R)}{(\mu - 1)} - \dfrac{(\mu'_V - \mu'_R)}{(\mu' - 1)}\right]$ or $\theta = \delta\,[\omega - \omega']$

If $\omega' > \omega$, the resultant dispersion is negative, i.e., opposite to that produced by the first prism.

RAINBOW

You must have observed most spectacular colour light band shown on earth i.e., rainbow. Indeed the traditional rainbow is sunlight spread out into its spectrum of colours and diverted to the eye of the observer by water droplets. The "bow" part of the word describes the fact that the rainbow is a group of nearly circular arcs of color all having a common center.

Rainbows are generated through refraction and reflection of light in small rain drops. The sun is always behind you when you face a rainbow, and that the center of the circular arc of the rainbow is in the direction opposite to that of the sun. The rain, of course, is in the direction of the rainbow i.e., rain drops must be ahead of you and the angle between your line-of-sight and the sunlight will be 40°– 42°.

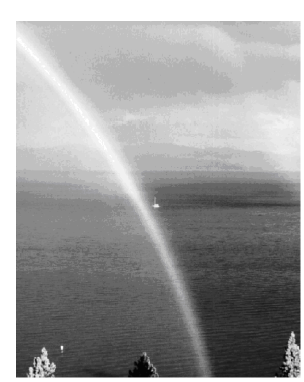


Fig. 2.19

After rain, there are still some tiny water droplets remained in the air. If there is sunshine, a white sunbeam will be reflected and refracted by these tiny droplets. Different colors of light have different refractivity. They will be reflected in slightly different directions inside a water droplet. Since, water is more dense than air, light is refracted as it enters the drop-red is bent less, blue more. Some of the light will reflect off the back of the drop if the angle is larger than the critical angle (48° for water)

The light is then refracted again as it leaves the drop (act like a small prism), the colours of white light have been dispersed.

- Violet light will leave the drop at an angle of 40° from the beam of sunlight
- Red light will leave the drop at an angle of 42° from the beam of sunlight.

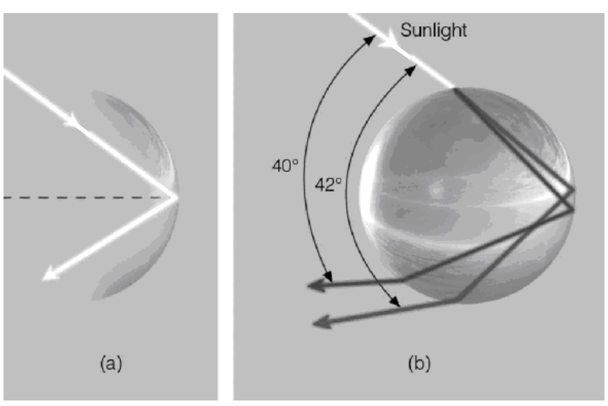


Fig. 2.20

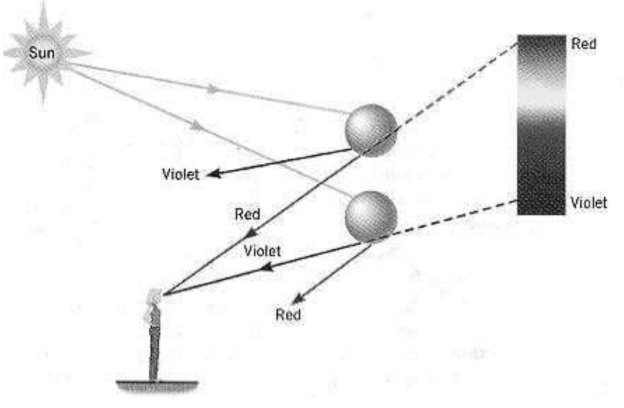


Fig. 2.21 : Rainbow formation

However, you cannot see the blue light and red light refracted from the same drop. So, many drops are involved in producing the rainbow, you can only see one wavelength of light refracted from one drop. So, to see a rainbow, you need to see light refracted from many drops. Hence, red will be on the top and blue will be on the bottom of the rainbow.

Primary and Secondary Rainbow

Both the primary and secondary rainbows are phenomena that are formed by the reflection and refraction of sunlight in tiny water droplets. *When a sun beam is being refracted twice and reflected once by the droplet, a primary rainbow will form. If the beam is being refracted twice and reflected twice, a secondary rainbow will form.* As the secondary rainbow is formed by one more reflection than the primary rainbow, it is much fainter and rare to see. On the other hand, since the paths of sunbeams in a primary rainbow and a secondary rainbow are different, the colours of the secondary rainbow are arranged in just the reverse order of the primary one.

(a) Primary rainbow *(b) Secondary rainbow*

Fig. 2.22

CHECK Point

A rainbow viewed from an airplane may form a complete circle. Where will the shadow of the airplane appear? Explain.

SOLUTION

A rainbow viewed from an airplane may form a complete circle because the earth doesnot come in the way of the airplane and rainbow and as a rainbow is a three dimensional cone of dispersed light it will appear as a complete circle. The shadow of the airplane will appear within the circle of the rainbow.

ATMOSPHERIC REFRACTION

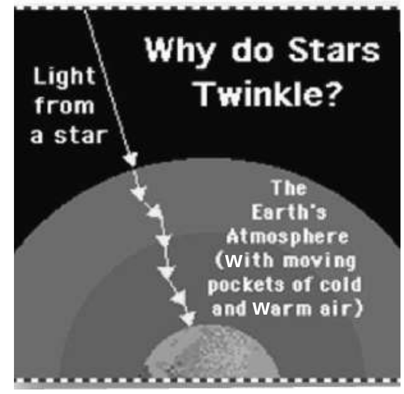


Fig. 2.23

The density of air in the atmosphere is not the same everywhere. It is greatest at the earth's surface and goes on decreasing as we move higher. The refractive index of air depends on its density-higher the density of air, greater its refractive index. The changes in refractive index of earth's atmosphere or air give rise to many phenomena like twinkling of stars, advance sunrise and delayed sunset etc.

Twinkling of stars

The scientific name for the twinkling of stars is stellar scintillation (or astronomical scintillation). Stars twinkle when we see them from the Earth's surface because we are viewing them through thick layers of turbulent (moving) air in the Earth's atmosphere.

Stars (except for the Sun) appear as tiny dots in the sky; as their light travels through the many layers of the Earth's atmosphere, the light of the star is bent (refracted) many times and in random directions (light is bent when it hits a change in density-like a pocket of cold air or hot air). This random refraction results in the star twinking out (it looks as though the star moves a bit, and our eye interprets this as twinkling).

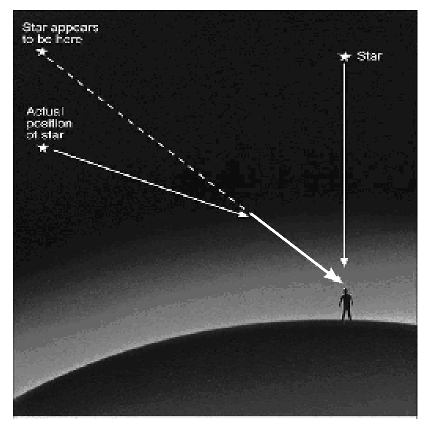


Fig. 2.24

Stars closer to the horizon appear to twinkle more than stars that are overhead - this is because the light of stars near the horizon has to travel through more air than the light of stars overhead and so is subject to more refraction. Also, planets do not usually twinkle, because they are so close to us; they appear big enough that the twinkling is not noticeable (except when the air is extremely turbulent).

Stars would not appear to twinkle if we viewed them from outer space (or from a planet/ moon that didn't have an atmosphere.

Since the atmosphere bends starlight towards the normal, the apparent position of the star is slightly different from its actual position. The star appears slightly higher (above) than its actual position when viewed near the horizon. Further, this apparent position of the star is not stationary, but keeps on changing slightly, since the physical conditions of the earth's atmosphere are not stationary.

Advance sunrise and delayed sunset

The actual sunrise takes place when the sun is just above the horizon. When the sun is just below the horizon, the light rays coming from it, on entering the earth's atmosphere suffer atmospheric refracton from a rarer medium to a denser medium. So, they bend towards the normal at each refraction. Due to the continuous refraction of light rays at each layer of the atmosphere, it follows a curved path as shown in Figure 2.25 and reaches the eyes of the observer at O.

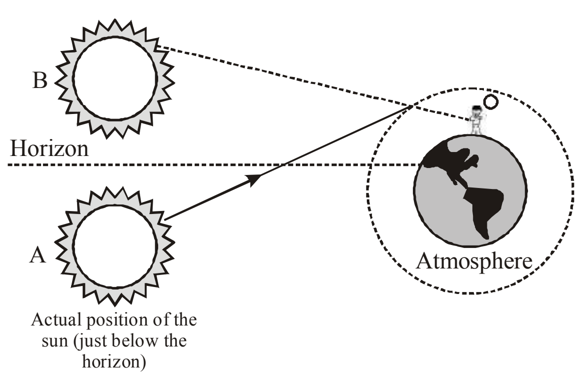


Fig. 2.25 Effect of atmospheric refraction at sunrise

For example, in Figure 2.25, the actual position of the sun is at A, just below the horizon but it appears to be at position B above the horizon. As a result, we can see the sun two minutes before it rises above the horizon in the morning. It is also due to atmospheric refraction that we can still see the sun for about two minutes even after the sun has set below the horizon. As a result, the time from sunrise to sunset is increased by about 4 (= 2 + 2) minutes because of atmospheric refraction.

SCATTERING OF LIGHT

The interplay of light with objects around us gives rise to several spectacular phenomena in nature. The blue colour of the sky, colour of water in deep sea, the reddening of the sun at sunrise and the sunset are some of the wonderful phenomena we are familiar with all this is because of scattering of light.
When sunlight enters the earth atmosphere, air and water vapour molecules will absorb part of the light and reradiate it to all directions. This is called scattering.

Rayleight scattering. According to Rayleigh's law of scattering the amout of scattered light $\alpha \frac{1}{(\text{wavelength})^4}$ so that the wavelength of violet, blue and indigo is small as compared to the rest of the colours. So sky appears blue in colour.

Tyndall Effect

When a beam of sunlight enters a dusty (or smoke filled) room through a window then path becomes visible due to scattering of light by dust or smoke particles this phenomenon is called tyndall effect.

Colour of the Sun at Sunrise and Sunset

At noon, the light of sun travels relatively shorter distance through earth's atmosphere thus appears white as only a little of blue and violet colours are scattered. Near the horizon , most of the blue light and shorter wavelengths are scattered and appears red.

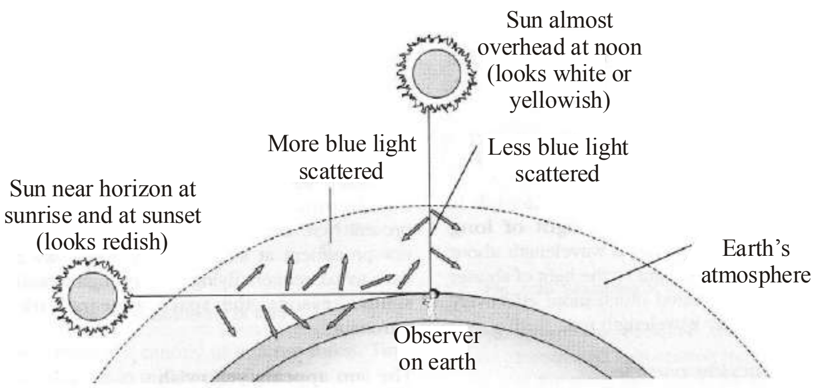


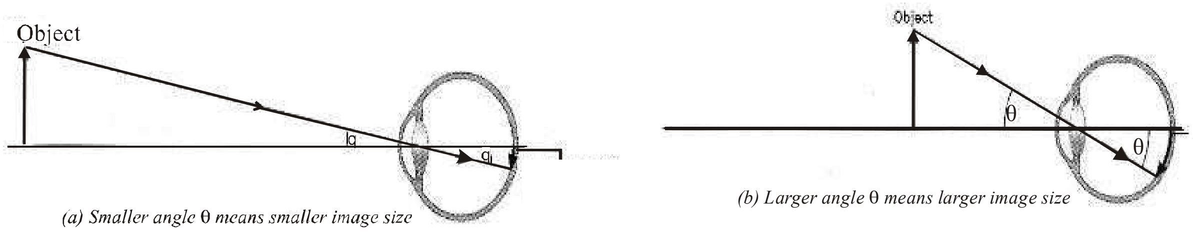
Fig. 2.26 Reddening of the sun at sunrise and sunset

Danger signals are of red colours, yellow colour head lights in foggy wather, white colours of cloud etc are some other applications of scattering of light.

CONNECTING TOPIC

OPTICAL INSTRUMENTS

The size of the image on the retina determines how large an object appears to be. However, the size of the image on the retina is difficult to measure. Alternatively, the angle θ subtended by the image can be used as an indication of the image size. Figure shows this alternative, which has the advantage that θ is also the angle subtended by the object and, hence, can be measured easily. The angle θ is called the angular size of both the image and the object. The larger the angular size, the larger the image on the retina, and the larger the object appears to be.
Angular magnification (X) = visual angle when object is placed at least distance of distinct vision
Visual angle with instrument



(a) Smaller angle θ means smaller image size
(b) Larger angle θ means larger image size

Fig. 2.27 : In both (a) and (b) the objects have the same size, but in (b) the image on the retina is larger because the object is closer to the eye. The angle θ is the angular size of both the image and the object.

Simple Microscope (Magnifying Glass or Reading Lens)

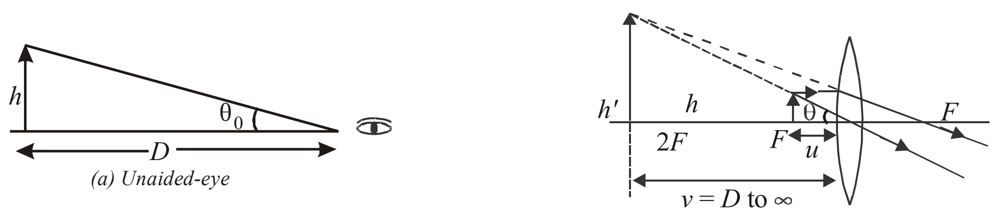
It is also known as magnifying glass or simply magnifier and consists of a convergent lens with object between its focus and optical centre and eye close to it. The image formed by it is erect, virtual enlarged and on same side of lens between object and infinity.

Magnification by a simple microscope

The magnifying power (MP) or angular magnification of a simple microscope (or an optical instrument) is defined as *the ratio* of *visual angle with instrument to the maximum visual angle for clear vision when eye is unaided (i.e., when the object is at least distance of distinct vision*)

i.e., $$MP = \frac{\text{Visual angle with instrument}}{\text{Max. visual angle for unaided eye}} = \frac{\theta}{\theta_0}$$

Case 1: Eye focussed at near point i.e., the image is formed at a distance *D* from the lens/eye



(a) Unaided-eye

Fig. 2.28

(b) Eye with instrument simple microscope

In this case, $v = D$

$$M = \frac{v}{u} = v \times \frac{1}{u} = v \times \left(-\frac{1}{f} + \frac{1}{v}\right)$$

Now, according to our sign convention v is equal to ($-D$) here.

$$\therefore\ M = (-D) \times \left(-\frac{1}{f} + \frac{1}{-D}\right) \quad \text{or} \quad M = 1 + \frac{D}{f} \quad \text{........... (A)}$$

Case 2: Eye focussed at infinity (Normal adjustment)

In this case, we find out angular magnification. If the object is viewed directly by the eye, keeping the object at the near point, then

$$\theta_0 = \frac{O}{D} \quad \text{........... (1)}$$

Now, let us find the angle subtended by its image, if the image is formed at ∞. In this case, the object will have to be kept at the focus of the lens.

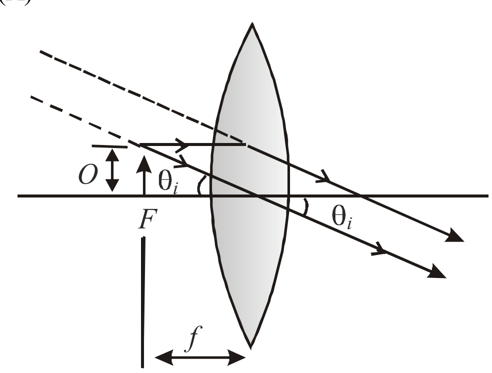


Fig. 2.29

In this case, $$\theta_i = \frac{O}{f} \quad \therefore \quad M = \frac{\theta_i}{\theta_0} = \frac{O/f}{O/D} \quad \text{or} \quad M = \frac{D}{f} \quad \text{........... (B)}$$

This is one less than the magnification when the image is formed at the near point, but, naturally, viewing is more comfortable and the difference in magnification usually small.

For example, if we want a magnification of six, *f* required will be 5 cm in the first case (taking D = 25 cm) and (D/6 = 25/6) $\approx$ 4 cm is the second case.

For all practical purposes, it is not possible to have magnification > 10 through a simple microscope.

USES

The watch makers use of convex lens to have a magnified view of the small parts of the watch. The magnified glass is also used to see slides. It is also used in laboratories to note vernier readings.

CONNECTING TOPIC

CHECK Point

The angle subtended at the eye by an object is equal to the angle subtended at the eye by the virtual image produced by a magnifying glass. In what sense then does a magnifying glass provide angular magnification?

SOLUTION

In magnifying glass the object is placed closer than 25 cm, which produce image at 25 cm. This closer object has larger angular size than the same object at 25 cm. In this way although the angle subtended by virtual image and object is same at eye but angular magnification is achieved.

Compound Microscope

It consists of two convergent lenses of short focal lengths and apertures arranged co-axially. Lens (of focal length f_0) facing the object is called objective or field lens while the lens (of focal length f_e) facing the eye, eye-piece or ocular. The objective has a smaller aperture and smaller focal length than eye-piece and the separation between objective and eye-piece can be varied.

Magnification of a compound microscope

M_0, linear magnification due to the objective

$$= \frac{I_1}{O} = \frac{A_1B_1}{AB} \quad \text{or} \quad \frac{A_1B_1}{PQ} \qquad \dots(1)$$

Now Δs PQF_1 and $B_1A_1F_1$ are similar,

$$\therefore \frac{A_1B_1}{B_1F_1} = \frac{PQ}{PF_1}$$

or $$\frac{A_1B_1}{PQ} = \frac{B_1F_1}{PF_1} = \frac{L}{f_0} \qquad \dots(2)$$

Put eg. (2) in (1) to get $$M_0 = \frac{L}{f_0} \qquad \dots(3)$$

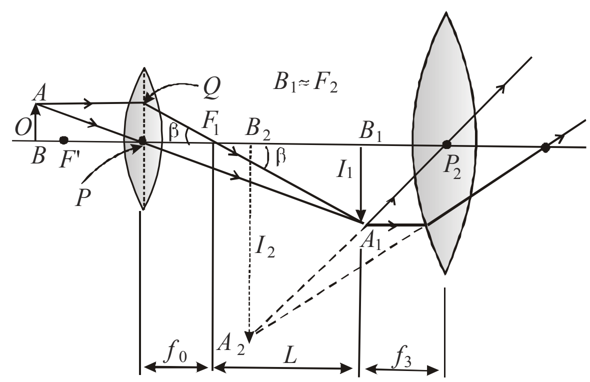


Fig. 2.30 Compound microscope

Now, let the eye is focussed at ∞. This means A_1B_1 (the image by objective) is made at the focus of the eyepiece. Angular magnification by eyepiece (i.e., a simple microscope, as already dealt with), M_e will thus be

$$M_e = \frac{D}{f_e} \qquad \dots(4)$$

$\therefore$ Total magnification, $M = M_0 \times M_e$ or $M = \frac{L}{f_0} \times \frac{D}{f_e}$

where, for all practical purposes L is approximately equal to the length of the compound microscope, and $D = 25$ cm, and f_0 and f_e are the focal lengths of the objective and eyepiece respectively.

If the eye is focussed at near point, M_e will be (as already derived in case of a simple microscope) = $(1 + D/f_e)$.

Therefore the total magnification will become, $$M = \frac{L}{f_0} \times \left(1 + \frac{D}{f_e}\right)$$

Telescope

Telescope is used to provide angular magnification of distant objects. It is of many types, general categories are :

(i) Refracting type (lenses are used) (ii) Reflecting type (mirrors are used)

(iii) Astronomical, to view celestial objects (iv) Terrestial, to view objects on earth.

Prism binoculars are also terrestial telescopes.

Astronomical Type Telescope (Refracting Type)

A refracting type astronomical telescope, used to see the distant objects at large distances, consists of objective, i.e., a converging lens, or lens combination of larger focal length f_0 and larger aperture, and an eyepiece, i.e., also a converging lens, or lens combination, but of smaller focal length f_e and smaller aperture, placed coaxially.

Magnifying power (M)

Magnifying power (M), also called angular magnification of a telescope is defined as *the ratio of the visual angle subtended by the final image at the eye and the visual angle subtended by the object when the object lies in the actual position*. (In contrast to the definition of magnifying power of a microscope, the object is not placed at the near point in case of telescope)

$$M = \frac{\beta}{\alpha} = \frac{\tan\beta}{\tan\alpha} \quad (\because \alpha, \beta \text{ are small})$$

$$M = \frac{A_1B_1 / EB_1}{A_1B_1 / OB_1} \quad (\text{in } \Delta AB_1O \text{ and } \Delta\ AB_1E) \Rightarrow M = \frac{OB_1}{EB_1}$$

Using sign convention and taking u_e as object distance for eyepiece, we get

$$M = \frac{+f_0}{-u_e} = -\frac{f_0}{u_e} \quad \text{... (1)}$$

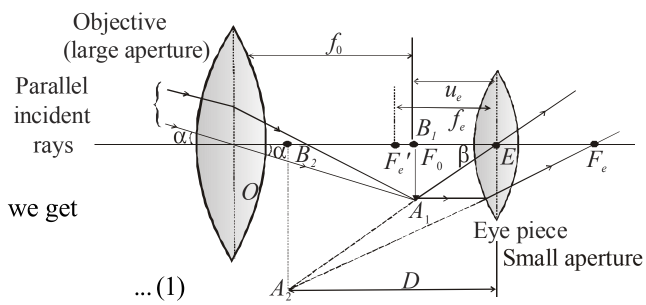


Fig. 2.31 Astronomical type telescope

This is the general formula for magnifying power of a telescope.

Magnifying power M, if eye is focussed at near point

For the eyepiece, $v = -D$, $v = -u_e$, $f = +f_e$, where , D = minimum distance of distinct vision

Using lens formula, we get $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ or, $\frac{1}{-D} - \frac{1}{-u_e} = \frac{1}{f_e}$

$$\therefore \quad \frac{1}{u_e} = \frac{1}{f_e} + \frac{1}{D} = \frac{1}{f_e}\left(1 + \frac{f_e}{D}\right) \quad \text{... (2)}$$

Put eq. (2) in (1), we get

$$M = -\frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right) \quad \text{... (3)}$$

In this case, the length of the telescope L $= f_0 + u_e$.

Magnifying power M when eye is focussed at ∞ (normal adjustment)

In this case, as already explained, we have $u_e = -f_e$ ... (4)

Put eq. (4) in (1) to get

$$M = \frac{f_0}{f_e} \quad \text{... (5)}$$

In this case, the length of the telescope L $= f_0 + f_e$.

This is the reason why the focal length of objective is taken large and of eyepiece small in case of a telescope. This also increases the resolving power of the telescope.

Further, linear or lateral magnification does not convey much meaning in case of a telescope because the size of final images too is negligible compared to actual size of the objects which are generally planets or stars.

Difference between Compound Microscope and Astronomical Telescope

Compound Microscope	Astronomical Telescope
1. It is used to increase visual angle of near tiny objects.	1. It is used to increase visual angle of distant large objects.
2. In it field and eye lens both are convergent, of short focal length and aperture.	2. In it objective lens is of large focal length and aperture while eye lens of short focal length and aperture and both are convergent.
3. Final image is inverted, virtual and enlarged and at a distance D to ∞ from the eye.	3. Final image is inverted, virtual and enlarged at a distance D to ∞ from the eye.
4. MP does not change appreciably if field and eye lens are interchanged [MP $\sim$ (LD / $f_0 f_e$)]	4. MP becomes (1/m^2) times of its initial value if objective and eye-lenses are interchanged as MP ~ [f_0 / f_e]
5. MP is increased by decreasing the focal length of both the lenses.	5. MP is increased by increasing the focal length of objective lens (and by decreasing the focal length of eye-piece.

LENS CAMERA

In it a converging lens whose aperture and distance from the film can be adjusted is used. Usually object is real and between ∞ and $2F$, so the image is real, inverted diminshed and between F and $2F$ as shown in figure.

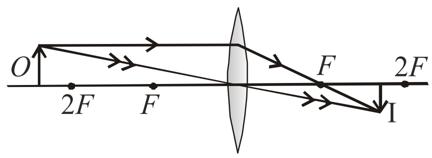


Fig. 2.32

In photography of an object, the image is first focused on the film by adjusting the distance between lens and film (called focusing). After focusing, aperture is set to a specific value (for desired effect) and then film is exposed to light for a given time through a shutter. I is the intensity of light, S is the light transmitting area of lens and t is the exposure time, then for proper exposure, $I \times S \times t = \text{constant}$

However, light transmitting area of a lens is proportional to the square of its aperture D, so above expression reduces to

$$I \times D \times t = \text{constant}$$

(1) If aperture is kept fixed, $I \times t = \text{constant}$

(2) If intensity is kept fixed, $D^2 \times t = \text{constant}$ i.e., Time of exposure $\propto \dfrac{1}{(\text{aperture})^2}$

Increasing the time of exposure by reducing the aperture increases the depth of field.

$$f\text{-number} \propto \frac{\text{focal length}}{\text{aperture}}; \qquad \text{Aperture} \propto \frac{1}{f\text{-number}}$$

$$\text{Time of exposure} \propto (f\text{-number})$$

The following table will explain this relationship in detail.

f-No.	2	$2.8 \approx 2\sqrt{2}$	4	$5.6 \approx 4\sqrt{2}$	8
$(f\text{-No.})^2$	4	8	16	32	64

MISCELLANEOUS SOLVED EXAMPLES

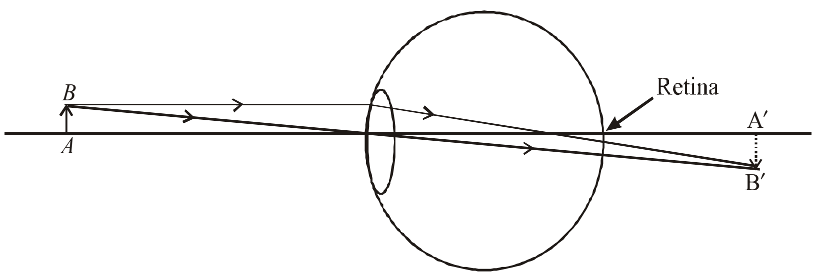
1. A person needs a lens of power –5.5 dioptres for correcting his distant vision. For correcting his near vision he needs a lens of power +1.5 diopters. What is the focal length of the lens required for correcting (i) distant vision, and (ii) near vision?

Sol. (i) Focal length of distance viewing $= \frac{1}{\text{Power}} \times 100\text{cm} = \frac{-100}{5.5}\text{cm} = -18.18\,\text{cm}.$

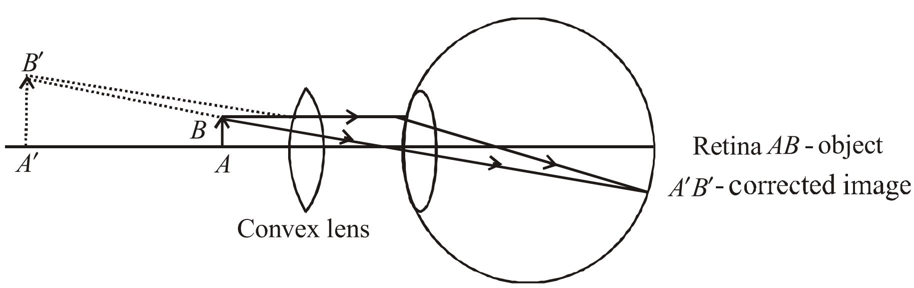
(ii) Focal length in near vision $= \frac{100}{1.5}\text{cm} = 66.6$ cm.

2. Make a diagram to show how hypermetropia is corrected. The near point of a hypermetropic eye is 1 m. What is the power of the lens required to correct this defect? Assume that the near point of the normal eye is 25 cm.

Sol. Hypermetropic eye



Corrected hypermetropic eye



To correct the defect, the image of an object at 25 cm should be brought at 100 cm.

$\therefore \quad \frac{1}{f} = \frac{1}{v} - \frac{1}{u} = \frac{1}{-100} - \frac{1}{-25}$ i.e., $\frac{1}{f} = \frac{-1}{100} + \frac{1}{25} = \frac{-1+4}{100} = \frac{3}{100}$

$\therefore \quad f = +\frac{100}{3} = +33.3$ cm

So, a convex lens of focal length 33.3 cm Or, Power, $P = \frac{100}{33.3} = 3.0\,D$ is required.

3. Why is a normal eye not able to see clearly the objects placed closer than 25 cm?

Sol. The maximum accommodation of a normal eye is reached when the object is at a distance of 25 cm from the eye. The focal length of the eye lens cannot be decreased below this minimum limit. Thus, an object placed closer than 25 cm cannot be seen clearly by a normal eye because all the power of accommodation has already been exhausted.

4. A farsighted person cannot focus clearly an object that are less than 145 cm from his eyes. To correct this problem, the person wear eyeglasses that are located 2.0 cm in front of his eyes. Determine the focal length that will permit this person to read a newspaper at a distance of 32.0 cm from his eyes.

Sol. The near point is 145 cm and eyeglasses are 2.0 cm in front of the eyes. Therefore, $v = -145 + 2 = -143$ cm.
The object is placed 32.0 cm from the eyes so, $u = +30.0$ cm.
The focal length is obtained from equation

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \frac{1}{(30.0\text{ cm})} + \frac{1}{-143\text{ cm}} = 0.026\text{ cm}^{-1}$$

Hence, $f = 38$ cm.

5. A certain eye has a near point of 11.0 cm and a far point of 15.0 cm. (a) What is the refractive power of the lens that is required to place the far point at infinity ? (b) What is the refractive power of the lens required to yield a near-point distance of 25 cm?

Sol. (a) We want to move the far point to infinity, so

$$\frac{1}{f} = \frac{1}{\infty} + \frac{1}{(-0.15\text{m})} = -6.7\text{ diopters}$$

(b) For the near point at 25 cm :

$$\frac{1}{f} = \frac{1}{0.25\text{ m}} + \frac{1}{-0.11\text{ m}} = -5.1\text{ diopters}$$

6. A figure divided into squares, each of size 1mm^2, is being viewed at a distance of 9 cm through a magnifying glass (a converging lens of focal length 10 cm) held close to the eye. (i) What is the magnification (image size/object size) produced by the lens ? How much is the area of each square in the virtual image ?
(ii) What is the angular magnification (magnifying power) of the lens ? (iii) Is the magnification in
(i) equal to the magnifying power in (ii) ? Explain.

Sol. (i) Here, $u = -9$ cm, $f = 10$ cm. Now, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ or $\frac{1}{v} = \frac{1}{f} + \frac{1}{u}$

or, $\frac{1}{v} = \frac{1}{10} + \frac{1}{-9} = \frac{-9+10}{-90} = -\frac{1}{90}$ or $v = -90$ cm.

Magnification, $m = \frac{v}{x} = \frac{-90}{-9} = 10$

Since, magnification is 10 therefore the area of each square in the virtual image is $10 \times 10 \times 1$ mm^2 i.e., 100 mm^2.

(ii) Angular magnification, $\propto = \frac{D}{u} = \frac{-25}{-9} = 2.78$

(iii) No, magnification of an image by a lens and angular magnification (or magnifying power) of an optical instrument are two separate things. The latter is the ratio of the angular size of the object (which is equal to the angular size of the image even if the image is magnified) to the angular size of the object if placed at the near point (25 cm). Thus, magnification magnitude is $\left|\frac{v}{u}\right|$ and magnifying power is $\frac{25}{|u|}$. Only when the image is located at the near point ($|v| = 25$ cm), are the two quantities equal.

7. A lady uses +1.5D glasses to have normal vision from 25 cm onwards. She uses a 20D lens as a magnifying glass to see an object. Calculate the maximum magnifying power if she uses the magnifying glass (a) together with her glass (b) without her glass.

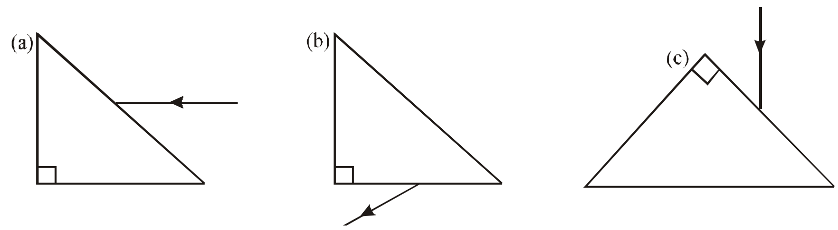
Sol. (a) In this case, magnifying power, $M = 1 + \frac{D}{f} = 1 + PD = 1 + 20 \times \frac{1}{4} = 6$

(b) Focal length of glasses $= \frac{100}{1.5} = \frac{1000}{15} = \frac{200}{3}$

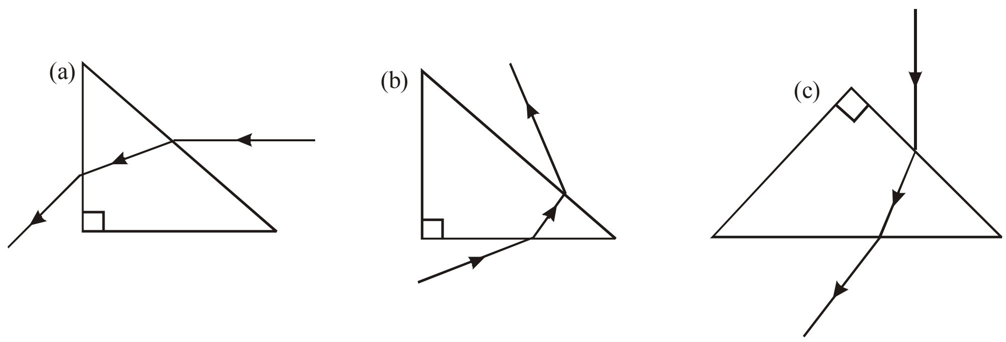
$\frac{1}{v} - \frac{1}{-25} = \frac{3}{100}$ or $\frac{1}{v} = \frac{3}{200} - \frac{1}{25} = \frac{3-8}{200} = -\frac{5}{200} = -\frac{1}{40} \Rightarrow v = -40$ cm.

Now, magnifying power, $M = 1 + Pv = 1 + 20\left(\frac{40}{100}\right) = 1 + 8 = 9$

8. Complete the path of the monochromatic ray of light in each (a), (b), (c) of the right angled isosceles triangle. Refractive index of the material of right angled isosceles triangle is 1.5 (figure).



Sol.



9. The refracting angle of the prism is 60°. What is the angle of incidence for minimum deviation ? The refractive index of material of prism is $\sqrt{2}$.

Sol. For minimum deviation, $r = A/2 = 60/2 = 30^0$

From snell's law $\dfrac{\sin i}{\sin r} = \mu$ or $\sqrt{2} = \dfrac{\sin i}{\sin 30^0}$

$\therefore \quad \sin i = \dfrac{1}{2} \times \sqrt{2} = \dfrac{1}{\sqrt{2}} = \sin 45^o$

Therefore angle of incidence, $i = 45^o$

10. The intensity of scattered light varies inversely as nth power of wavelength (λ) of incident ligth where,

(a) $n = 2$ (b) $n = 1$ (c) $n = 4$ (d) $n = -4$

Sol. (c) According to Rayleigh, intensity of scattered light $\propto \dfrac{1}{(\text{wavelength } \lambda)^4}$ $\therefore \quad n = 4$

SOLVED EXAMPLES BASED ON CONNECTING TOPICS

11. White light passes through a thin prism of angle 6°. If the refractive indices for the red and violet colours are 1.641 and 1.659, respectively, what is the angular dispersion produced by the prism?

Sol. Given: Angle of prism, $\angle A = 6°$; $\mu_R = 1.641$; $u_v = 1.659$; angular dispession $\theta = ?$

The angular dispersion produced by the prism

$$\theta = (\mu_V - \mu_R)A = (1.659 - 1.641)6° = 0.018 \times 6° = 0.108°$$

12. The crown glass has the refractive indices 1.51 and 1.49 for the blue and red lights, respectively, and the flint glass has the refractive indices 1.77 and 1.73 for the blue and red lights, respectively. A beam of white light is incident on a combination of two thin isosceles prisms, one of crown glass of angle $A = 6°$ and other of flint glass of unknown angle A'. If there is no net deviation of the light in passing through the combination, calculate the angle A′ and the net angular dispersion produced by the combination.

Sol. The net deviation of light produced by the combination of two prisms is zero and therefore,

$$(\mu_y - 1)A + (\mu_y - 1)A' = 0$$

$$\Rightarrow \quad A' = -\frac{(\mu_y - 1)A}{(\mu_y' - 1)} = -\frac{[(\mu_V + \mu_R)/2 - 1]A}{[(\mu_V' + \mu_R')/2 - 1]} = -\frac{(\mu_V + \mu_R - 2)A}{(\mu_V' + \mu_R' - 2)} = -\frac{(1.51 + 1.49 - 2)6°}{(1.77 + 1.73 - 2)} = 4°$$

where the minus sign indicates that the second prism of flint glass of angle A′ = 4° is placed inverted with respect to the first prism of crown glass of angle A = 6°.

Then the net angular dispersion of light produced by the combination is

$$\theta = (\mu_V{}' - \mu_R{}')A' + (\mu_V - \mu_R)A$$

$$= -(1.77 - 1.73)4° + (1.51 - 1.49)6° \;= -0.04 \times 4° + 0.02 \times 6 = -0.04$$

13. A compound microscope has the magnifying power of magnitude 30. The focal length of it's eyepiece is 5 cm. If the final image is formed at the least distance of distinct vision *D* = 25 cm, calculate the magnification produced by the objective.

Sol. The magnifying power of compound microscope is

$$M = m_0 \times m_e = -\left(\frac{v_0}{f_0} - 1\right) \times \left(1 + \frac{D}{f_e}\right)$$

Therefore, the magnification produced by the objective is

$$m_0 = \frac{M}{m_e} = \frac{M}{\left(1 + \frac{D}{f_e}\right)} = \frac{-30}{\left(1 + \frac{25}{5}\right)} = -5$$

where the minus sign indicates that the image formed by the objective is inverted.

14. An astronomical telescope, consisting of an objective of focal length 60 cm and eyepiece of focal length 3 cm, is focussed on moon whose final image is formed at the least distance of distinct vision D = 25 cm from the eyepiece. If the angular size of moon is 0.5°, what will be the linear size of the final image of moon?

Sol. The magnifying power of telescope has the magnitude

$$|M| = \frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right) = \frac{60}{3}\left(1 + \frac{3}{25}\right) = 22.4$$

Then, the angular size of the final image of moon will be

$$= |M| \times 0.5° = 22.4 \times 0.5° = 11.2° = 11.2 \times \frac{\pi}{180}\text{ radian}$$

and it's linear size will be $= D\left(11.2 \times \frac{\pi}{180}\right)\text{cm} = 25\left(11.2 \times \frac{\pi}{180}\right)\text{cm} = 25 \times 0.2\text{ cm} = 5\text{ cm}$

1 EXERCISE

Fill in the Blanks :

DIRECTIONS: *Complete the following statements with an appropriate word / term to be filled in the blank space(s).*

1. The coloured diaphragm between the cornea and the lens is ....

2. The middle point of the iris has a hole, which is called ....

3. The screen on which the image is formed by the lens system of the human eye is called ....

4. For young adult with normal vision, least distance of distinct vision = ...

5. The closest distance at which the eye can focus clearly is called the ....

6. For a normal eye, the range of vision is from ....

7. The eye which suffers from myopia as well as from hypermetropia is said to suffer from ....

8. The eye which cannot simultaneously see with the same distinctness all objects or lines making different inclinations is said to suffer from ....

9. The defect of the eye due to which a person is unable to distinguish between certain colours, known as ....

10. The ability of the eye to focus both near and distant objects, by adjusting its focal length, is called the ....

11. The smallest distance, at which the eye can see objects clearly without strain, is called the .... of the eye.

12. The splitting of white light into its component colours is called ....

13. .... causes the blue colour of sky and the reddening of the Sun at sunrise and sunset.

14. Sunlight comprises .... colours.

True / False :

DIRECTIONS: *Read the following statements and write your answer as true or false.*

1. Lens which is used for correcting the presbyopia defect of the eye is concave.

2. The colour that deviates maximum while passing through a glass prism is violet.

3. Water droplets act as tiny prism in the formation of rainbow.

4. The transparent spherical membrane covering the front of the eye is known as cornea.

5. The eye which can see near object clearly is said to suffer from hypermetropia.

6. The eye which cannot see distant objects clearly is said to suffer from myopia.

7. Colour blindness is a genetic disorder which occurs by inheritance.

8. In Myopia the image of distant objects is focussed before the retina.

9. Hypermetropia is corrected by using a convex lens of suitable power.

10. A person suffering from myopia cannot see distant objects clearly.

11. The focal length of a given lens depends on the surrounding medium.

12. A dentist uses a convex mirror to view the inner parts of a patient's mouth.

13. The solar spectrum in general is an absorption spectrum.

14. The sun looks red at sunset because most of the blue light in sunrays is scattered leaving behind red and yellow lights.

15. Clouds look white because water droplets of clouds scatter all colours of light equally.

16. The sun is visible two minutes before the actual sunrise due to atmospheric refraction.

Match the Following :

DIRECTIONS (Qs. 1-2) : *Each question contains statements given in two columns which have to be matched. Statements (A, B, C, D) in column I have to be matched with statements (p, q, r, s) in column II.*

1. Match the following :

Column I	**Column II**
(A) Inverted crown-flint glass prism	(p) Deviation $\propto \frac{1}{\text{dispersive power}}$
(B) Achromatism	(q) Deviation without dispersion
(C) Hollow prism	(r) Absence of chromatic aberration
(D) Glass slab	(s) Dispersion without deviation

2. Column II gives lens that can be use to correct the defect of vision given in column I, match them correctly.

Column I	**Column II**
(A) Myopia	(p) Convex lens
(B) Hypermetropia	(q) Concave lens
(C) Astigmatism	(r) Cylindrical lens
(D) Presbyopia	(s) Bi-focal lens

Very Short Answer Questions:

DIRECTIONS : *Give answer in one word or one sentence.*

1. When a monochromatic light passes through a prism, will it show dispersion?
2. What do you mean by a pure spectrum?
3. What is the common name for short sightedness?
4. Name the defect which is corrected by using an astigmatic lens.
5. Will a star appear to twinkle if seen from free space (say moon) ?
6. What prevents rainbows from being seen as complete circles?
7. What is responsible for the rainbow-coloured fringe commonly seen at the edges of a spot of white light from the beam of lantern or slide projector?
8. What is the essential condition for observing a rainbow ?
9. A hypermetropic person has problem in driving without spectacles, comment on this.
10. A short-sighted person cannot see clearly beyond 2 m. Calculate power of the lens required to correct his eye to normal vision.
11. A myopic person can see things clearly only when they lie between 10 cm and 100 cm from his eye. Which lens will enable him to see the moon clearly ?
12. A person can see the objects lying between 25 cm and 10 m from his eye. His vision can be corrected by using lens of power – 0.1 D. Is the statement true or false ?
13. Which part of the eye causes the first refraction ?
14. Which part of the eye gives the characteristic colour of the eye ?
15. What is the distance at which a watch repairer holds the watch when he is wearing a magnifying glass, if his distance of most distinct vision is 30 cm ? Assume that he is not aware of the action of a convex lens.

Short Answer Questions :

DIRECTIONS : *Give answer in 2-3 sentences.*

1. Can a beam of white light when passed through a hollow prism give spectrum ? Explain.
2. What is colour blindness?
3. How do we see colours?
4. A person having a myopic eye uses a concave lens of focal length 50 cm. What is the power of the lens ?
5. Why do different coloured rays deviate differently in the prism?
6. Why does a diamond sparkle?
7. Who do stars twinkle on a clear night?
8. A person having the nearest distance of distinct vision of 32 cm uses a reading lens of 8 cm focal length. What is the magnification of his reading lens ?
9. A man who wears glasses of power 3 dioptre must hold a newspaper at least 25 cm away to see the print clearly. How far away would the newspaper have to be if he took off the glasses and still wanted clear vision?
10. Why does it take some time to see objects in a dim room when you enter the room from bright sunlight outside ?
11. Does a single raindrop illuminated by sunlight disperse a spectrum of colours? Does a viewer see a spectrum from a single far away drop?
12. How can we determine the focal length and power of the concave lens required to correct a myopic eye?
13. How can we determine the focal length and power of the convex lens required to correct a hypermetropic eye?
14. A 45 year old person is suffering from a defect in his vision due to which he uses spectacles of bi-focal lenses.
(a) Which defect he is suffering from?
(b) What is a bi-focal lens?
15. What is dark adaptation of the eye?
16. A person having short sight (near sight) unable to see clearly beyond 2 m develops presbyopia by which he is unable to read a book held closer than 1m. Prescribe lenses of suitable power for distant vision and near vision.

Long Answer Questions :

DIRECTIONS : *Give answer in four to five sentences.*

1. Why does it take some time to see objects in a dim room when you enter the room from bright sunlight outside?
2. A prism causes dispersion of white light while a rectangular glass block does not. Explain.
3. When yellow paint and blue paint are mixed we get green colour. When yellow light and blue light are mixed, white light is obtained. Give reasons.
4. Explain why in day light an object appears red when seen through a red glass and black when seen through a blue glass?
5. Explain working of human eye.
6. Explain the following terms. used in relation to defects in vision and correction provided by them:
(a) Myopia (b) Astigmatism
(c) Bi-focal lenses (d) Far sightedness

2 EXERCISE

Text-Book Questions :

1. What is meant by power of accommodation of the eye?
2. A person with a myopic eye cannot see objects beyond 1.2 m distinctly. What should be the type of the corrective lens used to restore proper vision ?
3. What is the far point and near point of the human eye with normal vision ?
4. A student has difficulty in reading the blackboard while sitting in the last row. What could be the defect the child is suffering from ? How can it be corrected ?

Text-Book Exercise :

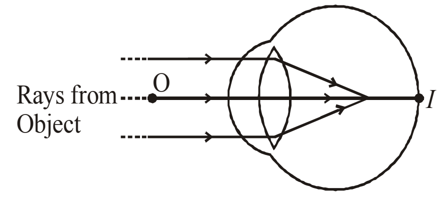
1. The human eye can focus objects at different distances by adjusting the focal length of the eye lens. This is due to
   (a) presbyopia (b) accommodation
   (c) near-sightedness (d) far-sightedness.
2. The human eye forms the image of an object at its
   (a) cornea (b) iris
   (c) pupil (d) retina.
3. The least distance of distinct vision for a young adult with normal vision is about
   (a) 25 m (b) 2.5 cm
   (c) 25 cm (d) 2.5 m
4. The change in focal length of an eye lens is caused by the action of the
   (a) pupil (b) retina
   (c) ciliary muscles (d) iris
5. A person needs a lens of power –5.5 dioptres for correcting his distant vision. For correcting his near vision he needs a lens of power +1.5 dioptre. What is the focal length of the lens required for correcting (i) distant vision, and (ii) near vision ?
6. The far point of a myopic person is 80 cm in front of the eye. What is the nature and power of the lens required to correct the problem ?
7. Make a diagram to show how hypermetropia is corrected. The near point of a hypermetropic eye is 1m. What is the power of lens required to correct this defect ? Assume that the near point of the normal eye is 25 cm.
8. Why is a normal eye not able to see clearly the objects placed closer than 25 cm?
9. What happens to the image distance in the eye when we increase the distance of an object from the eye?
10. Explain why the planets do not twinkle.
11. Why does the Sun appear reddish early in the morning?
12. Why does the sky appear dark instead of blue to an astronaut ?

Exemplar Questions :

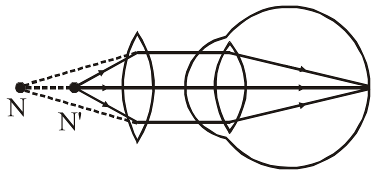
1. A student sitting at the back of the classroom cannot read clearly the letters written on the blackboard. What advice will a doctor give to her? Draw ray diagram for the correction on this defect.
2. How will you use two identical prisms so that a narrow beam of white light incident on one prism emerges out of the second prism as white ligth? Draw the diagram.
3. Is the position of a star as seen by us its true position? Justify your answer.
4. How does refraction take place in the atmosphere? Why do stars twinkle but not the planets?

Hots Questions :

1. A person with a myopic eye cannot see objects beyond 1.2m distinctly. What should be the type of the corrective lens used to restore proper vision ?
2. A person with a defective eye-division is unable to see the objects nearer than 1.5m. He wants to read books at a distance of 30m. Find the nature, focal length and power of the lens he needs in his spectacles.
3. Study the figure given below and answer the questions that follow.



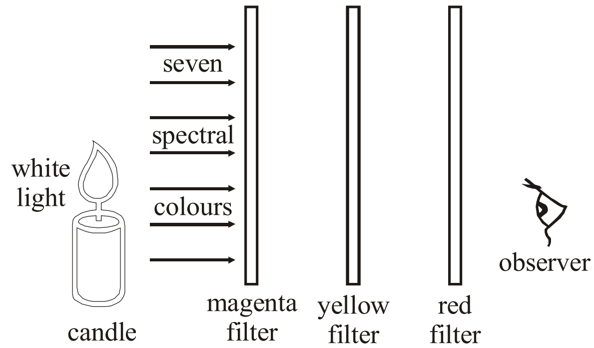
   (a) Which defect of vision has been shown in the figure ?
   (b) What do the points O and I represent ?
   (c) Which lens is used to correct this defect ?
   (d) Redraw the figure with the corrective lens.
4. In the diagram given below, a defective eye has been corrected. Study the diagram and answer the questions that follow.



(a) Name the defect which has been corrected.
(b) Name the point N.
(c) Why a convex lens, instead of a concave lens, has been used ?
(d) Redraw the figure of the defective eye without the corrective lens.

5. One eye is sufficient to form the image of an object. What is the advantage of having two eyes ?

6.



In the above diagram, extend the lines to show which of the seven spectral colours would pass through the magenta filter, the yellow filter and finally the red filter. Label the colour of each line.

7. How is presbyopia different from hypermetropia ?

3 EXERCISE

Single Option Correct :

DIRECTIONS: *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. The human eye forms the image of an object at its
(a) cornea (b) iris
(c) pupil (d) retina

2. The least distance of distinct vision for a young adult with normal vision is about
(a) 25 m (b) 2.5 cm
(c) 25 cm (d) 2.5 m

3. The change in focal length of an eye lens is caused by the action of the
(a) pupil (b) retina
(c) ciliary muscles (d) iris

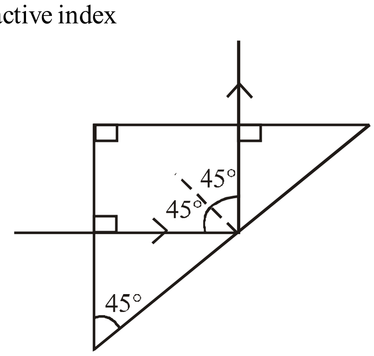
4. A near sighted person cannot see distinctly beyond 50 cm from his eye. The power in diopter of spectacle lenses which will enable him to see distant objects clearly is
(a) +50 (b) –50
(c) +2 (d) –2

5. The following one is not a primary colour
(a) Yellow (b) Red
(c) Green (d) Blue

6. Fraunhofer lines in the sun's spectrum are present because
(a) Vapours of certain elements present in the atmosphere absorb certain colours
(b) The temperature of the sun is very high
(c) The sun does emit certain light
(d) Certain elements present in the sun interfere

7. When a mirror is rotated an angle the reflected ray moves through double that angle, the instrument based on the above principle is
(a) Periscope (b) Odometer
(c) Refractometer (d) Sextant

8. A light ray is incident perpendicularly to one face of a 90° prism and is totally internally reflected at the glass-air interface. If the angle of reflection is 45°, we conclude that the refractive index



(a) $n > \frac{1}{\sqrt{2}}$ (b) $n > \sqrt{2}$
(c) $n < \frac{1}{\sqrt{2}}$ (d) $n < \sqrt{2}$

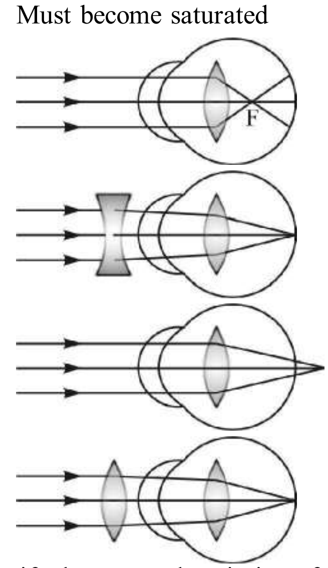
9. Rainbow is caused due to
(a) Reflection of sun light air
(b) Dispersion of sun light from water drops
(c) Refraction of sun light from water drops
(d) Diffraction of sun rays from water drops

10. In the visible spectrum the colour having the shortest wavelength is
(a) Green (b) Red
(c) Violet (d) Blue

11. The splitting of white light into several colours on passing through a glass prism is due to
(a) refraction (b) reflection
(c) interference (d) diffraction

12. At the moment dew formation starts on a cool night, the air
(a) Must loose all water vapour
(b) Must remain unsaturated
(c) Must get mixed up with some other vapour
(d) Must become saturated

13. 1. 2. 3. 4.



Identify the wrong description of the above figures
(a) 1 represents far-sightedness
(b) 2 correction for short sightedness
(c) 3 represents far sightedness
(d) 4 correction for far-sightedness

14. At sun rise or at sun set the sun appears to be reddish while at mid-day it looks white. This is because
(a) Scattering due to dust particles and air molecules causes this phenomenon
(b) The sun is cooler at sun rise or at sunset
(c) Refraction causes this phenomenon
(d) Diffraction sends red rays to the earth at these times.

15. Sometimes blurred and less sharply defined images are formed. This defect is called
(a) Chromatic aberration (b) Spherical aberration
(c) Blurred lens (d) None of the above

16. A person cannot see objects clearly which are nearer than 75 cms from his eyes, the disease he is suffering from is
(a) Astigmatism (b) Myopia
(c) Hypermetropia (d) Presbyopia

17. On entering a glass prism, sun rays are
(a) Deviated but not dispersed
(b) Deviated and dispersed
(c) Dispersed but not deviated
(d) Neither deviated nor dispersed.

18. A piece of cloth looks red in sun light. It is held in the blue portion of a solar spectrum, it will appear
(a) red (b) black
(c) blue (d) white

19. To get line spectrum, the substances are excited in their
(a) solid state (b) molecular state
(c) gaseous state (d) atomic state

20. The frequency of light whose wavelength is 5000 Å is
(a) 15×10^{13} cycles per second
(b) 5000 cycles per second
(c) 6×10^{14} cycles per second
(d) 15×10^{16} cycles per second

21. The pupil of the eye changes in size to adjust for
(a) objects at different distances
(b) objects of different sizes
(c) different colors
(d) different amounts of light

22. To use a magnifying glass, the object should be placed
(a) as close to the lens as possible
(b) just within the lens' focal point
(c) just beyond the focal point
(d) some distance beyond the focal point

23. A camera employs a .... lens to form .... images
(a) diverging .... real
(b) diverging .... virtual
(c) converging ... real
(d) converging ... virtual

24. In the eye, the position of the image on the retina is adjusted by changing the
(a) position of the lens
(c) diameter of the pupil
(b) focal length of the lens
(d) length of the eyeball

25. What power lens is needed to correct for nearsightedness where the uncorrected far point is 250 cm?
(a) +2.5 diopters (b) –2.5 diopters
(c) + 0.4 diopters (d) –0.4 diopters

26. What power lens is needed to correct for farsightedness where the uncorrected near point is 250 cm?
(a) + 3.6 diopters (b) – 3.6 diopters
(c) + 0.28 diopters (d) – 0.28 diopters

27. In a room, artificial rain is produced at one end and a strong source of white light is switched on at the other end. To observe the rainbow an observer must
(a) Look anywhere in the room
(b) Look towards the source
(c) Look towards the raindrops
(d) Look in a direction equally inclined to the source of raindrops

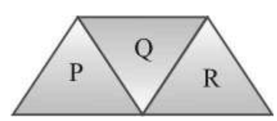
28. Astigmatism can be corrected by
(a) Bifocal lenses
(b) Cylindrical lenses
(c) Concave lenses
(d) Planoconvex lenses

29. The convex lens is not used
(a) in camera
(b) as glasses to correct for short sight
(c) as glasses to correct for light sight
(d) all of the above

30. When blue light is used in a thin convex lens then the focal length is found to be f. If instead red light is used, then the focal length will be
(a) equal to f
(b) less than f
(c) greater than f
(d) nothing can be predicted

31. Dispersion is the term used to describe
(a) the propagation of light in straight lines
(b) The splitting of a beam of light into component colours
(c) The bending of a beam of light when it strikes a mirror
(d) The change that takes place in white light after passage through red glass.

32. A given ray of light suffers minimum deviation in an equilateral prism P. Additional prisms Q and R of identical shape and material are now added to P as shown in the figure. The ray will suffer



(a) greater deviation (b) same deviation
(c) no deviation (d) total internal reflection

33. In a glass prism
(a) Blue light is dispersed more than red light
(b) Red light is dispersed more than blue light
(c) Both red light and blue light are equally dispersed
(d) None of these

34. An optician while testing the eyes finds the vision of a patient to be 6/12. By this he means that
(a) The person can read the letters of 6 inches from a distance of 12 m
(b) The person can read the letters of 12 inches from 6 m
(c) The person can read the letters of 6 m which the normal eye can read from 12 m
(d) The focal length of eye lens had become half that of the normal eye

35. A person cannot see objects clearly beyond 50 cm. The power of the lens to correct the vision is
(a) +5 D (b) –0.5 D
(c) –2 D (d) +2 D

36. A long sighted person has a minimum distance of distinct vision of 50 cm. He wants to reduce it to 25 cm. He should use a

(a) Concave lens of focal length 50 cm
(b) Convex lens of focal length 25 cm
(c) Convex lens of focal length 50 cm
(d) Concave lens of focal length 25 cm

37. A long-sighted person cannot see objects clearly at a distance less than 40 cm. from his eye. The power of the lens needed to read an object at 25 cm. is
(a) – 2.5 D (b) + 2.5 D
(c) – 6.25 D (d) + 1.5 D

38. Twinkling of stars is on account of
(a) Large distance of stars and storms in air
(b) Small size of stars
(c) Large size of stars
(d) Large distance of stars and fluctuations in the density of air.

39. White light is incident at an angle to the surface of a triangular piece of glass. Which color of light deviates most from its original path after leaving the glass?
(a) red (b) orange
(c) green (d) blue

40. The middle vascular coat that darkens the eye chamber and prevents refraction by absorbing the light rays is
(a) choroid (b) sclera
(c) retina (d) cornea

41. When light rays enter the eye, most of the refraction occurs at the
(a) crystalline lens
(b) outer surface of the cornea
(c) iris
(d) pupil

42. When the light is bright,
(a) the iris makes the pupil expand
(b) the iris and the pupil contract
(c) the iris and the pupil remain as they are
(d) none of the above

43. The eyelens .... light rays to form real, inverted and highly diminished image on the ....
(a) converges, retina
(b) diverges, retina
(c) converges, pupil
(d) diverges, pupil

44. The surface of retina has about 125 million light sensitive
(a) rods only
(b) cones only
(c) rods and cones
(d) neither rods nor cones

45. The 'far point' of a normal human eye is
(a) 25 cm (b) 25 m
(c) 100 m (d) at infinity

46. The property related to the sense of continuity of vision is called
(a) persistence of vision
(b) colour blindness
(c) optical illusion
(d) none of these

47. When the ciliary muscles are relaxed, the eyelens is .... and distant objects can be seen clearly.
(a) thin (b) thick
(c) inclined (d) none of these

48. While looking at nearby objects, the ciliary muscles .... the eyelens so as to .... its focal length.
(a) contract, increase (b) contract, decrease
(c) expand, increase (d) expand, decrease

49. The change in focal length of an eyelens to focus the image of object at varying distances is done by the action of the
(a) pupil (b) ciliary muscles
(c) retina (d) blind spot

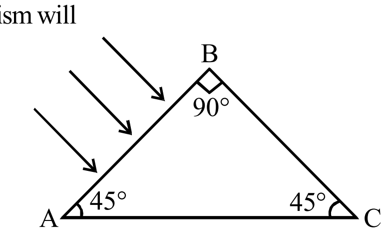
50. Which of the following statement is correct?
(a) A person with myopia can see distant objects clearly
(b) A person with hypermetropia can see nearby objects clearly
(c) A person with myopia can see nearby objects clearly
(d) A person with hypermetropia cannot see distant objects clearly

51. A person cannot see distinctly objects kept beyond 2 m. This defect can be corrected by using a lens of power
(a) + 0.5 D (b) – 0. 5 D (c) + 0. 2 D (d) – 0. 2 D

52. Astigmatism occurs when the cornea does not have a truly spherical shape. This defect can be cured by the use of a
(a) concave lens (b) cylindrical lens
(c) convex lens (d) plano- convex lens

53. How should people wearing spectacles work with a microscope?
(a) They should keep on wearing their spectacles
(b) They should never use the microscope
(c) They should take off their spectacles
(d) They may either put on their spectacles or they may take off their spectacles

54. A beam of light consisting of red, green and blue colours is incident on a right-angled prism as shown. 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) separate part of the red colour from the green and blue colours.
(b) separate part of the blue colour from the red and green colours.
(c) separate all the three colours from one another.
(d) not separate even partially any colour from the other two colours.

55. The rod cells correspond to
(a) the colour of light (b) the source of light
(c) the intensity of light (d) none of these

56. Which of the following statements is correct regarding the propagation of light of different colours of white light in air?
(a) Red light moves fastest
(b) Blue light moves faster than green light
(c) All the colours of the white light move with the same speed
(d) Yellow light moves with the mean speed as that of the red and the violet light

57. When a ray passes through a prism,
(a) it goes undeviated
(b) it remains parallel to the base
(c) it bends towards the base
(d) none of the above

58. At a particular minimum value of angle of deviation, the refracted ray becomes
(a) parallel to the base of the prism
(b) perpendicular to the base of the prism
(c) inclined at 45° w.r.t. base of the prism
(d) none of these

59. Twinkling of stars is due to atmospheric
(a) dispersion of light by water droplets
(b) refraction of light by different layers of varying refractive indices
(c) scattering of light by dust particles
(d) internal reflection of light by clouds

60. Which of the following phenomena of light are involved in the formation of a rainbow?
(a) Reflection, refraction and dispersion
(b) Refraction, dispersion and total internal reflection
(c) Refraction, dispersion and internal reflection
(d) Dispersion, scattering and total internal reflection

61. The clear sky appears blue because
(a) blue light gets absorbed in the atmosphere
(b) ultraviolet radiations are absorbed in the atmosphere
(c) violet and blue lights get scattered more than lights of all other colours by the atmosphere
(d) light of all other colours is scattered more than violet and blue colour lights by the atmosphere

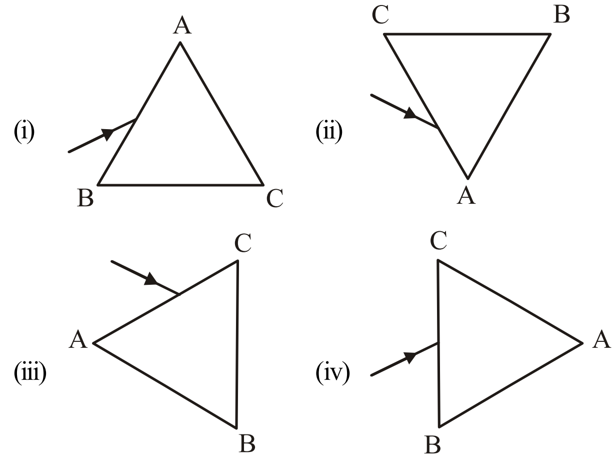
62. At noon the sun appears white as
(a) light is least scattered
(b) all the colours of the white light are scattered away
(c) blue colour is scattered the most
(d) red colour is scattered the most

63. Which of the following phenomena contributes significantly to the reddish appearance of the sun at sunrise or sunset?
(a) Dispersion of light
(b) Scattering of light
(c) Total internal reflection of light
(d) Reflection of light from the earth

64. The bluish colour of water in deep sea is due to
(a) the presence of algae and other plants found in water
(b) reflection of sky in water
(c) scattering of light
(d) absorption of light by the sea

65. A student sitting on the last bench can read the letters written on the blackboard but is not able to read the letters written in his text book. Which of the following statements is correct?
(a) The near point of his eyes has receded away
(b) The near point of his eyes has come closer to him
(c) The far point of his eyes has come closer to him
(d) The far point of his eyes has receded away

66. A prism ABC (with BC as base) is placed in different orientations. A narrow beam of white light is incident on the prism as shown in Figure. In which of the following cases, after dispersion, the third colour from the top corresponds to the colour of the sky?



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

67. The danger signals installed at the top of tall buildings are red in colour. These can be easily seen from a distance because among all other colours, the red light
(a) is scattered the most by smoke or fog
(b) is scattered the least by smoke or fog
(c) is absorbed the most by smoke or fog
(d) moves fastest in air

68. The bluish colour of water in deep sea is due to
(a) the presence of algae and other plants found in water
(b) reflection of sky in water
(c) scattering of light
(d) absorption of light by the sea

More than One Option Correct :

DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

1. The human eye can focus objects at different distances by adjusting the focal length of the eye lens. Choose those options which are not accountable for this happening.
(a) presbyopia (b) accommodation
(c) near-sightedness (d) far-sightedness

2. The change in focal length of an eye lens is not caused by the action of the
(a) pupil (b) retina
(c) ciliary muscles (d) iris

3. The following is/are a primary colour
(a) Yellow (b) Red
(c) Green (d) Blue

4. When a mirror is rotated an angle the reflected ray moves through double that angle, the instruments which are not based on the above principle, are
(a) Periscope (b) Odometer
(c) Refractometer (d) Sextant

5. In case of hypermetropia
(a) The image of near objects is formed in front of retina
(b) The image of near objects is formed behind the retina
(c) A concave lens should be used for correction
(d) A convex lens cannot be used for correction

6. Astigmatism is / are
   (a) Bifocal lenses (b) Cylindrical lenses
   (c) Concave lenses (d) Planoconvex lenses
7. The defect that may occur in a lens are
   (a) spherical aberration and chromatic aberration
   (b) coma and astigmation
   (c) distortion
   (d) none of the above
8. Out of the following, which statements are correct
   (a) Sunlight filtering through a tree often makes circular patches on the ground because sun is round
   (b) A beam of white light passing through a hollow prism gives no spectrum
   (c) The number of images observable between two parallel plane mirrors is infinite
   (d) A virtual object placed between the pole and the principal focus of a convex mirror produces an image which is virtual, diminished and upright.
9. Due to refraction of light in atmosphere
   (a) Stars appear to twinkle
   (b) The sun appears to be oval in morning and evening
   (c) The period of visibility of the sun is increased
   (d) The phenomena of mirage and looming take place
10. Out of the following, select the correct statements
   (a) Refractive index varies inversely as the fourth power of the wavelength of light.
   (b) When the moon is near the horizon, it appears bigger. This is due to optical illusion.
   (c) The colour of light which travels with the maximum speed in glass is red.
   (d) If sun is shining brightly in one part of the sky after rain, two rainbows are usually observed.
11. The optical phenomenon which Newton's theory of light failed to explain is
   (a) interference (b) polarization
   (c) diffraction (d) none of the above three
12. A convex mirror is not used
   (a) by a dentist (b) for shaving
   (c) as a rear view mirror in vehicles
   (d) as a light reflector for obtaining a parallel beam of light.

Passage Based Questions :

DIRECTIONS : *Study the given paragraph(s) and answer the following questions.*

Passage - I

Human eye is spherical in shape and has diameter of about 2.5 cm. Sclerotic is a tough, opaque and white substance forming the outermost coating of the eyeball. The front portion is sharply curved and covered by a transparent protective membrane called the 'cornea'. Inner to the sclerotic there is a layer of black tissue called as choroids consisting of a mass of blood vessels, which nourishes the eye. The black colour does not reflect the light and hence rules out the blurring of image by reflection within the eyeball.

Behind the cornea, the space is filled with a liquid called the aqueous humour and behind that a crystalline lens. 'Iris' is a muscular diaphragm lying between the aqueous humour and the crystalline lens. Iris has an adjustable opening in the middle called the pupil of the eye. The pupil appears black because all the light entering is absorbed by the 'retina', which covers the inside of the rear part of the ball. Iris controls the amount of light emerges because the retina absorbs nearly all the light, which falls upon it. This is done by varying the aperture of the pupil with the help of the iris. In dim light the iris dilates the pupil so that more light can enter in. When the light is bright the pupil contracts.

The crystalline lens divides the eyeball into two chambers. The chamber between the cornea and the lens is called the anterior chamber filled with a fluid called aqueous humour while the chamber between the lens and the retina is called the posterior chamber which is filled with a transparent gelatinous substance called vitreous humour.

The refractive indices of the cornea, pupil lens and fluid portion of the eye are quite similar. So, when a ray of light enters the eye, it is refracted at the cornea. This refraction produces a real inverted and diminished image of distant objects on the retina.

When the object is kept at different distances then, we may expect the image to be formed at different distances from the lens. It means, it may not form on the retina always.

But in reality it is not so. Image is always formed on the retina. This is possible because the curvature of the crystalline lens is altered by ciliary muscles. When the eye is focused on infinity the muscles are relaxed and the eye lens remains thin. If the object is brought near by, the curvature increases so that the image can be formed on the retina. This property of the eye lens is called accommodation.

1. The change in focal length of an eye lens to focus the image of objects at varying distances is done by the action of ________
   (a) pupil (b) ciliary muscles
   (c) retina (d) blind spot
2. The fluid between the retina and the lens is called ______
   (a) aqueous humour (b) vitreous humour
   (c) aqua (d) humus
3. The part of the eye where optic nerves enter the eye
   (a) pupil (b) ciliary muscles
   (c) retina (d) blind spot
4. The inner back surface of the eyeball is called
   (a) pupil (b) ciliary muscles
   (c) retina (d) blind spot

Passage - II

The ciliary muscles of eye control the curvature of the lens in the eye and hence can alter the effective focal length of the system. When the muscles are fully relaxed, the focal length is maximum. When the muscles are strained the curvature of lens increases (that means radius of curvature decreases) and focal length decreases. For a clear vision the image must be on retina. The image distance is therefore fixed for clear vision and it equals the distance of retina from eye-lens. It is about 2.5 cm for a grown-up person.

A person can theoretically have clear vision of objects situated at any large distance from the eye. The smallest distance at which a person can clearly see is related to minimum possible focal length. The ciliary muscles are most strained in this position. For an average grown-up person minimum distance of object should be around 25 cm.

A person suffering for eye defects uses spectacles (Eye glass). The function of lens of spectacles is to form the image of the objects within the range in which person can see clearly. The image of the spectacle-lens becomes object for eye-lens and whose image is formed on retina.

The number of spectacle-lens used for the remedy of eye defect is decided by the power of the lens required and the number of spectacle-lens is equal to the numerical value of the power of lens with sign. For example power of lens required is +3D (converging lens of focal length 100/3 cm) then number of lens will be +3.

For all the calculations required you can use the lens formula and lens maker's formula. Assume that the eye lens is equiconvex lens. Neglect the distance between eye lens and the spectacle lens.

5. Minimum focal length of eye lens of a normal person is
(a) 25 cm (b) 2.5 cm (c) 25/9 cm (d) 25/11 cm

6. Maximum focal length of eye lens of normal person is
(a) 25 cm (b) 2.5 cm (c) 25/9 cm (d) 25/11 cm

7. A nearsighted man can clearly see object only upto a distance of 100 cm and not beyond this. The number of the spectacles lens necessary for the remedy of this defect will be
(a) +1 (b) – 1 (c) +3 (d) – 3

Assertion & Reason :

DIRECTIONS : *Each of these questions contains an Assertion followed by reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.
(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.
(c) If **Assertion** is **correct** but **Reason** is **incorrect**.
(d) If **Assertion** is **incorrect** but **Reason** is **correct**.

1. **Assertion:** Myopia is due to the increased converging power of the eye lens.
Reason: Myopia can be corrected by using spectacles made from concave lenses.

2. **Assertion:** The twinkling of stars is due to the fact that refractive index of the earth's atmosphere fluctuates.
Reason: In cold countries, the phenomenon of looming (*i.e.*, ship appears in the sky) takes place, because refractive index of air decreases with height.

3. **Assertion:** When we see an object, the image formed on the retina is real and inverted.
Reason: If the magnification of a system is less than one, then the image formed is inverted.

4. **Assertion:** Rainbow is an example of the dispersion of sunlight by the water droplets.
Reason: Light of shorter wavelength is scattered much more than light of larger wavelength.

Multiple Matching Questions :

DIRECTIONS : *Following question has four statements (A, B, C and D....) given in Column I and 5 statements (p, q, r, s and t.....) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II.*

1.

Column I	Column II
(A) Spectrometer	(p) refraction
(B) Mirage	(q) deviation without dispersion
(C) Hollow prism	(r) to measure angle of prism
(D) Glass slab	(s) to measure the dispersion
	(t) dispersion without deviation

	A	B	C	D
(a)	s,r	r, p	q	q
(b)	s	p	q	r, t
(c)	p,q	s	r,s,t	q
(d)	q,s	q,r	s	s,t

Integer/ Numeric Questions :

DIRECTIONS : *Following are integer based/Numeric based questions. Each question, when worked out will result in one integer or numeric value.*

1. A watch-repairer has his near point at 20 cm. If he uses a magnifying glass of power 20 dioptre, what is the magnification that he gets?

2. A person suffering from long sightedness cannot see objects before 1.5 m distinctly. Suggest a lens with proper focal length and power for his remedy. Assume the near point of the normal eye to be 25 cm.

3. Calculate the power of a concave lens of focal length 25 cm.

4. Calculate the power of a convex lens of focal length 25 cm.

5. The power of a concave lens used for correcting a myopic eye is – 0.6 D. Find the far point of the eye.

6. The power of a convex lens used to correct a hypermetropic eye is + 0.8 D. Find the near point of the eye. Assume the least distance of distinct vision to be 25 cm.

7. The far point of a myopic person is 80 cm in front of the eye. What is the nature and power of lens required to correct the problem ?

8. A person cannot see objects nearer than 75 cm from his eyes while a person with normal vision can see objects upto 25 cm from his eyes. Find the nature, the focal length and the power of the correcting lens used for the defective vision.

9. A person can see clearly only up to 3 metres. Prescribe a lens for spectacles so that he can see clearly up to 12 metres. Defect is myopia.

10. The far point of a myopic person is 80 cm in front of the eye. What is the power of the lens required to enable him to see the distant objects clearly ?

11. A ray of light is travelling in water medium falls on the water-air interface at an angle of 45° with the vertical. Will it be possible by the ray of light to come out of the water surface?

4 ADVANCED EXERCISE
BASED ON CONNECTING TOPICS

DIRECTIONS (Qs. 1-20) : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. Angle of deviation (δ) by a prism (refractive index = μ, and supposing the angle of prism A to be small) can be given by

(a) $\delta = (\mu - 1)A$ (b) $\delta = (\mu + 1)\text{A}$

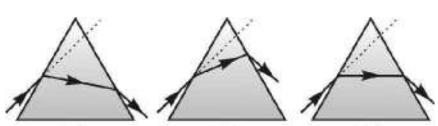
(c) $\delta = \dfrac{\sin(A+\delta)/2}{\sin(A/2)}$ (d) $\delta = \dfrac{\mu - 1}{\mu + 1}A$

2. Prism angle of a prism is 10°. Their refractive index for red & violet colour is 1.51 and 1.52, respectively. Then dispersive power will be

(a) 0.5 (b) 0.15

(c) 0.019 (d) 0.032

3. The figures represent three cases of a ray passing through a prism of angle A. The case corresponding to minimum deviation is



(1) (2) (3)

(a) 1 (b) 2

(c) 3 (d) None of these

4. Prism angle and refractive index for a prism for a 60° and 1.414. Angle of minimum deviation will be

(a) 15° (b) 30°

(c) 45° (d) 60°

5. Diameter of the moon is 3.5×10^3 km and its distance from earth is 3.8×10^5 km. It is seen by a telescope whose objective and eyepiece have focal lengths 4m and 10cm respectively. The angular diameter of the image of the moon will be nearly

(a) 5° (b) 10°

(c) 20° (d) 25°

6. A telescope consisting of an objective of focal length 60 cm and a single–lens eye-piece of focal length 5 cm is focussed at a distant object in such a way that parallel rays emerge from the eye-piece. If the object subtends an angle of 2° at the objective, then the angular width of the image will be

(a) 10° (b) 24°

(c) 50° (d) 1/6°

7. The angle of minimum deviation of a ray of light of glass prism is greatest for the light of colour

(a) violet (b) orange

(c) yellow (d) red

8. A direct vision spectrometer uses the phenomenon of

(a) Diffraction

(b) Interference without deviation

(c) Dispersion without deviation

(d) Deviation without dispersion

9. For seeing a cricket match, we prefer binoculars to the terrestrial telescope, because

(a) Binoculars give three-dimensional view

(b) Terrestrial telescope gives inverted image

(c) To avoid chromatic aberration

(d) To have larger magnification

10. One of the refracting surfaces of a prism is silvered, and the angle of prism is A. It is found that a ray of light incident at an angle of incidence 2A after suffering refraction return back through the same path due to reflection from the second silvered refracting surface. Then the refractive index of the material of the prism is

(a) 2 sin A (b) 2 cos A

(c) tan A (d) ½ cos A

11. If for a given prism the angle of incidence is changed from 0° to 90°, the angle of deviation

(a) Increases

(b) Decreases

(c) First decreases and then increases

(d) First increases and then decreases

12. The refracting angle of a prism is A and the refractive index of the prism is cot A/2. The angle of minimum deviation is

(a) 180° – 3A (b) 180° + 2A

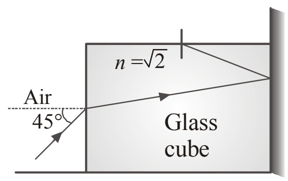
(c) 90° – A (d) 180° – 2A

13. A ray of light passing through a prism having $\mu = \sqrt{2}$ suffers minimum deviation. If angle of incident is double the angle of refraction within prism, than angle of prism is

(a) 30° (b) 45°

(c) 60° (d) 90°

14. Right face of a glass cube is silvered as shown. A ray of light is incident on left face of the cube as shown. The deviation of the ray when it comes out of the glass cube is



(a) 0°
(b) 90°
(c) 180°
(d) 270°

15. The focal length of the objective lens of a compound microscope is

(a) equal to the focal length of its eye piece
(b) less than the focal length of eye piece
(c) greater than the focal length of eye piece
(d) any of the above three

16. When the length of a microscope tube increases, its magnifying power

(a) decreases
(b) increases
(c) does not change
(d) may decrease or increase

17. In a compound microscope, the intermediate image is

(a) virtual, erect and magnified
(b) real, erect and magnified
(c) real, inverted and magnified
(d) virtual, erect and reduced

18. For a telescope to have large resolving power the

(a) focal length of its objective should be large
(b) focal length of its eye piece should be large
(c) focal length of its eye piece should be small
(d) aperture of its objective should be large

19. An astronomical telescope has an angular magnification of magnitude 5 for distant objects. The separation between the objective and the eye piece is 36 cm and the final image is formed at infinity. The focal length f_o of the objective and the focal length f_e of the eye piece are

(a) $f_o = 45$ cm and $f_e = -9$ cm
(b) $f_o = 7.2$ cm and $f_e = 5$ cm
(c) $f_o = 50$ cm and $f_e = 10$ cm
(d) $f_o = 30$ cm and $f_e = 6$ cm

20. A ray is incident at an angle of incidence i on one face of a prism of small angle *A* and emerges normally from the opposite surface. If the refractive index of the material of the prism is μ, the angle of incidence i is nearly equal to

(a) A/μ
(b) A/2μ
(c) μA
(d) μA/2

DIRECTIONS (Qs.21-24): *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

21. White light is incident on an equilateral prism. In the position of minimum deviation

(a) Angle of incidence is equal to angle of emergence
(b) The ray inside the prism is parallel to its base
(c) The angle of refraction inside the prism is equal to the angle of prism
(d) The dispersion of all colours is same

22. Spectrometer is used to measure

(a) angle of prism
(b) refractive index of material of a prism
(c) the dispersion
(d) none of the above

23. Consider the following statements :

A compound microscope is better than single lens microscope because

(a) it can produce larger magnification
(b) it has better resolution
(c) it produces images free of all defects of these statements
(d) all the above

24. A planet is observed by an astronomical refracting telescope having an objective of focal length 16 m and an eye-piece of focal length 2 cm

(a) the distance between the objective and the eye-piece is 16.02 m
(b) the angular magnification of the planet is 800
(c) the image of the planet is inverted
(d) the objective is larger than the eye-piece

DIRECTIONS (Qs. 25-26): *Study the given paragraph(s) and answer the following questions.*

Passage

A telescope has an objective of focal length 50 cm and eyepiece of focal length 5 cm. The distance of distinct vision is 25 cm. The telescope is focussed for distinct vision on a scale 200 cm away from the objective.

25. The separation between the objective and eyepiece (in cm) is.

(a) 56
(b) 28.20
(c) 70.80
(d) 87.24

26. The magnification produced is...........times.

(a) 2
(b) 4
(c) 6
(d) 8

DIRECTIONS (Qs. 27-29): *Each of these questions contains an Assertion followed by reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.
(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.
(c) If **Assertion** is **correct** but **Reason** is **incorrect**.
(d) If **Assertion** is **incorrect** but **Reason** is **correct**.

27. **Assertion :** There exists two angles of incidence for the same magnitude of deviation (except minimum deviation) by a prism kept in air.
Reason : In a prism kept in air, a ray is incident on first surface and emerges out of second surface. Now if another ray is incident on second surface (of prism) along the previous emergent ray, then this ray emerges out of first surface along the previous incident ray. This particle is called principle of reversibility of light.

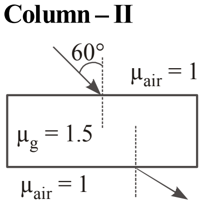
28. **Assertion:** The optical instruments are used to increase the size of the image of the object.
Reason: The optical instruments are used increase the visual angle.

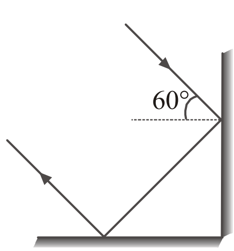
29. **Assertion:** The resolving power of a telescope is more if the diameter of the objective lens is more.
Reason: Objective lens of large diameter collects more light

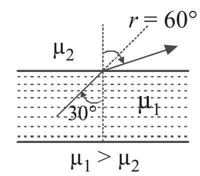
DIRECTIONS (Qs. 30) : *Following question has four statements (A, B, C and D....) given in Column I and 5 statements (p, q, r, s and t.....) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II.*

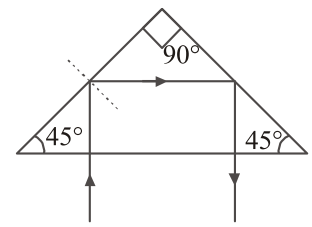
30. Angle of deviation is given in **Column -I** and ray diagram for angle of deviation in **Column -II**

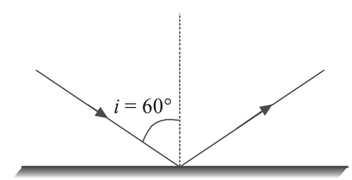
Column – I | **Column – II**

(A) 60° (p)


(B) 0° (q)


(C) 180° (r)


(D) 30° (s)


(t)


	A	B	C	D
(a)	t	p	q,s	r
(b)	r	t	q	r,t
(c)	p,s	q	r,s,t	r
(d)	p	q, r	s	s,t

DIRECTIONS (Qs. 31-35) : *Following are integer/numeric based questions. Each question, when worked out will result in one integer or numeric value.*

31. Prism angle of a prism is 10°. Their refractive indices for red and violet colour are 1.51 and 1.52 respectively. Then find the dispersive power.

32. Prism angle and refractive index for a prism are 60° and 1.414. What will be the angle of minimum deviation?

33. The angle of a crown glass (μ =1.52) prism is 5°. What should be the angle of a flint glass (μ = 1.63) prism, so that the two prisms together may be used in direct vision spectroscope ?

34. The length of a microscope is 14 cm and for relaxed eye the magnifying power is 25. The focal length of the eyepiece is 5cm. Calculate the distance of the object and the focal length of the objective.

35. The diameter of the moon is 3.5×10^3 km and its distance from earth is 3.8×10^5 km. It is seen by a telescope whose objective and eyepiece have focal lengths 4m and 10cm respectively. Determine the angular diameter of the image of the moon.

SOLUTIONS

Brief Explanations of Selected Questions

1 EXERCISE

Fill in the Blanks :

1. iris
2. pupil
3. retina
4. 25 cm.
5. near point
6. 25 cm to infinity
7. presbyopia.
8. astigmatism.
9. colour blindness
10. accommodation of the eye.
11. near point
12. dispersion.
13. Scattering of light
14. 7

True / False:

1. False
2. True
3. True
4. True
5. False
6. True
7. True
8. True
9. True
10. True
11. True
12. False
13. True
14. True
15. True
16. True

Match the Following :

1. (A) $\rightarrow$ s; (B) $\rightarrow$ r, p; (C) $\rightarrow$ q; (D) $\rightarrow$ q
2. (A) $\rightarrow$ q; (B) $\rightarrow$ p; (C) $\rightarrow$ r; (D) $\rightarrow$ s

Very Short Answer Questions :

1. No, it will not show any dispersion but will show only deviation.
2. A pure spectrum is the one in which the colours are separated from one another using a narrow source of light.
3. Myopia.
4. Spherical aberration.
5. No, because there is no atmosphere in free space for refraction to take place.
6. The earth comes in the way of the rainbow and prevents it to form a complete circle.
7. The rainbow - colored fringe formed at the edges of a spot of white light coming from a beam of lantern or slide projector is due to diffraction of light rays coming from different part of the beam.
8. Back of the observer must be towards the sun.
9. No, the statement is false. A hypermetropic person can observe far off objects without any problem.
10. –0.5 D
11. f = –1 m
12. True
13. Cornea causes the first refraction.
14. Iris gives the characteristic colour of the eye.
15. The distance of the watch from the eye must be such that its virtual image is formed at 30 cm from his eye.

Short Answer Questions :

2. Colour blindness is a defect of the eye due to which a person is unable to distinguish between certain colours, sometime even the primary colours.
3. The retina of human eye has a large number of light sensitive cells. These cells are of two types i.e., rod cells and cone cells. The rod shaped cells show response towards the intensity of light rays, while the cone shaped cells respond to colour. It is these cone cells, which make it possible for a man to see different colours and distinguish between them.
4. Focal length, f = – 50 cm (concave lens)
   Now, Power,
   $$P = \frac{1}{\text{f (in metre)}} = \frac{1}{-\frac{50}{100}\text{m}} = -\frac{100}{50} = -2$$
   Thus, the power of this concave lens is –2 dioptres
5. Different coloured rays deviate differently in the prism because the angle of refraction of different colours is different while passing through the glass prism.
6. The refractive index of diamond is very high. The faces of diamond are cut in such a way that the light entering into the diamond suffers total internal reflection repeatedly.
7. The continuously changing atmosphere causes refraction which is able to cause variation in the light coming from a point-sized star, thus the stars appear to be twinkling.
8. $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ $v = -32$ cm, $f = 8$ cm, $\therefore u = -32/5$
   Now $m = v/u = 5$
9. As here $u = -0.25$ m and f = 1 / P = (1/3) m, from lens formula $P = \frac{1}{f} = \frac{1}{v} - \frac{1}{u}$, we have $3 = \frac{1}{v} - \frac{1}{-0.25}$
   or $\frac{1}{v} = 3 - 4 = -1$ m
   i.e. $v = -1$ m
   i.e., the lens shifts the object from 25 cm to 1 m for clear

vision, i.e., his near point is 1m. So in absence of glasses, he must hold the newspaper at a distance of 1m away from his eyes for clear vision.

10. In the bright sunlight, iris causes the pupil to become smaller so that only a small portion of light enters the eye and rods of the retina are also adjusted in the same way. But when a person enters into a dimly-lit room, each iris takes some time to increase the diameter of the pupil, so that more amount of light can enter the eyes to see the object clearly and rod cells of the retina also take some time to adjust themselves to get the picture of the object in the dim light.

11. A single raindrop illuminated by sunlight disperse the light to produce seven colors of the spectrum.
A viewer cannot see a full spectrum from a single raindrop because the colours of the spectrum formed by a single raindrop are separated by a large distance. A viewer sees the colours of a continuous spectrum dispersed by different raindrops. Millions of drops produce the entire spectrum of visible light.

12. Let x be the distance of the actual far point from the eye and hence from the concave lens placed close to the eye. The rays coming from infinity, after refraction through the concave lens, appear to come from the far point F.

$\therefore\ u = -\infty,\ v = -x,\ f = ?$

By lens formula,

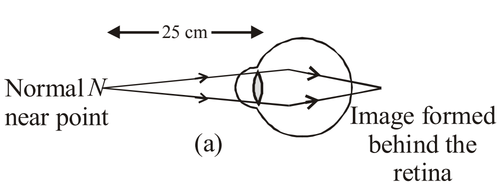
$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} = \frac{1}{-x} - \frac{1}{-\infty} = -\frac{1}{x} + 0 = -\frac{1}{x}$$

$\therefore$ Required focal length, $f = -x$

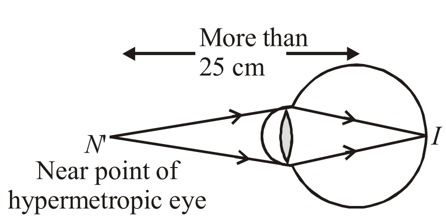
Required power, $P = \frac{1}{f} = -\frac{1}{x}$

The negative sign shows that the correcting lens is a concave lens.

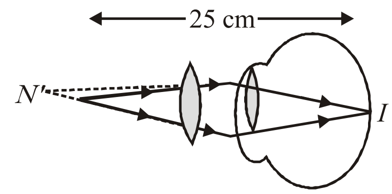
13.



(a)



(b)



Convex lens converges the rays as if they are coming from N

(c)

Let y = distance of the near point N' from the defective eye. Now the near point N of the normal eye is at distance $D = 25$ cm. The object placed at N forms its virtual image at N' Due to the convex lens.

$\therefore\ u = -D,\ v = -y,\ f = ?$

By lens formula

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} = \frac{1}{-y} - \frac{1}{-D} = \frac{y-D}{yD}$$

Required focal length, $f = \frac{yD}{y-D}$

$$\therefore \text{ Required power, } P = \frac{1}{f} = \frac{y-D}{yD}$$

As $y > D$, so both f and D are positive. That is the correcting lens must be a convex lens.

14. (a) The person is suffering from presbyopia.
(b) A bi-focal lens consists of both concave and convex lenses. The upper portion consists of a concave lens and the lower portion consists of a convex lens.

15. In a dark room or at very low level of illumination the supply of light sensitive chemicals in the rods of the retina increases to make the rods respond to that very low intensity of illumination; this takes half an hour to happen and this process is called dark adaptation.

16. For distant vision, defect is short sight
Focal length f = distance of defective far point = – 2m

$$\therefore P = -\frac{1}{2m} = -0.5 \text{ dioptre (concave)}$$

For near vision, u = normal distance of distinct vision = 0.25 m; v = defective near point = – 1 m (virtual image)

$$P = \frac{1}{f} = \frac{1}{v} - \frac{1}{u} = \frac{1}{-1} - \frac{1}{-0.25}$$

$$= -1 + 4 = 3 \text{ dioptre (convex)}$$

Long Answer Questions :

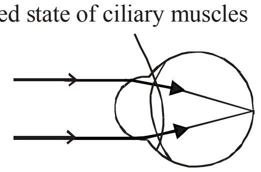
1. In the bright sunlight, iris causes the pupil to become smaller so that only a small portion of light enters the eye and rods of the retina are also adjusted in the same way. But when a person enters into a dimly-lit room, each iris takes some tome to increase the diameter of the pupil, so that more amount of light can enter the eyes to see the object clearly and rod cells of the retina also take some time to adjust themselves to get the picture of the object in the dim light.

2. In a prism the refraction of light takes place at the two slant surfaces. The dispersion of white light occurs at the first surface of prism where its constituent colours are deviated through different angles. At the second surface, these split colours suffer only refraction and they get further separated. But in a rectangular glass block, the refraction of light takes place at the two parallel surfaces. At the first surface, although the white light splits into its constituent colours on refraction, but these split colours on suffering refraction at the second surface emerge out in form of a parallel beam, which give an impression of white light.

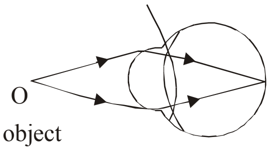
3. Yellow light is 'made up' of two of the primary colours, namely red and green. Hence, when this light is mixed with the light of the third primary colour, namely blue light, we get white light.
Yellow light + Blue light = (Red light + Green light) + Blue light = White light
The effect of mixing of two paints of different colours is not the same as that of mixing of two pure spectral lights. This is because each paint appears to have a colour that depends on the lights that it can reflect. Yellow paint is known to reflect red, green and yellow lights. Similarly blue paint reflects blue and green lights. Hence, when these two paints are mixed, the mixture can reflect only green light and thus appears green in colour.

4. We will have these observations if the given object is able to reflect red light but is not able to reflect blue light. This would be possible if the object is either of red or of yellow (= red + green) colour, as seen in normal day light.
The red (or yellow) object would appear red when seen through a red glass because only the red light, reflected by it (from day light), passes through this glass. The red (or yellow) object would appear black when seen through a blue glass because none of the lights (red or red + green) reflected by it (from day light) passes through this glass.

5. **Working of human eye :** When you look at an object, light rays from the object enter into the eye through cornea by aqeous humour which also acts as lens to refract maximum light. This light then passes through pupil which allows the required amount of light to pass through it. When this light falls on eye lens image is formed on retina. This is a real and inverted image. This image is sent to the brain through optical nerves in the form of electric signal and brain interpret the image into erect image.



(A) Eye-lens has its largest focal lenght



(B) Eye-lens has a shorter focal length

6. (a) **Myopia or short- sightedness:** In this defect a person can see nearby objects clearly but cannot see far off objects clearly. Here, either the eyeball becomes too longer or the focal length of the eye lens becomes too short. It can be corrected by using a concave lens of suitable focal length.
(b) **Astigmatism:** It is a defect of vision in which a person cannot simultaneously see both the horizontal and vertical views of an object with the same clarity. It is due to the irregular curvature of the cornea. It can be corrected by using a cylindrical lens.
(c) **Bi-focal lenses:** Some people suffer from both myopia and hypermetropia. Such people require bi-focal lenses. The upper part of the bi-focal lens is a concave lens used for distant vision while its lower part is a convex lens used for reading purposes.
(d) **Far sightedness or hypermetropia:** In this defect a person can see the far off objects clearly but he canot see nearby objects distinctly. Here, either the eyeball becomes too short or the focal length of the eye lens becomes too large. It can be corrected by using convex lens of suitable focal length.

2 EXERCISE

Text-Book Questions :

1. The ability of eye lens to change its focal length with the help of ciliary muscles is called accomodation power.
2. The person is suffering from myopia. This defect is corrected by using a concave lens of suitable focal length i.e., power.

$$\text{Power} = \frac{-1}{\text{far point (metre)}} = \frac{-1}{1.2} = \frac{-10}{12}$$
$$= \frac{-5}{6} = -0.83 \text{ dioptre}$$

3. A healthy human eye can see the objects at infinity distinctly. So far point is infinity. The eye can also see the nearly objects beyond 25 cm.
4. The student is suffering from myopia. It can be corrected by using concave lens of suitable focal length.

Text-Book Exercise :

1. (b)
2. (d)

3. (c) 25 cm

4. (c)

5. (i) Distant vision (ii) For near vision

$P = -\frac{1}{f(\text{metre})}$ $f = \frac{1}{P} = \frac{1}{1.5}$

$f = -\frac{1}{P} = \frac{1}{5.5} = \frac{-10}{55}$ $f = \frac{10}{15} \times 100 \text{ cm}$

$f = -\frac{2}{11} \text{m} = \frac{-2}{11} \times 100 \text{ cm}$ $f = \frac{200}{3} \text{ cm}$

$f = -\frac{200}{11} \text{cm} = -18.2 \text{ cm}$ $f = +66.67 \text{ cm}$

6. The lens used for correcting the disease is concave lens

$P = -\frac{1}{\text{far point (metre)}} = -\frac{1}{80 \text{ cm}} = \frac{-100}{80}$

$= -1.25$ D.

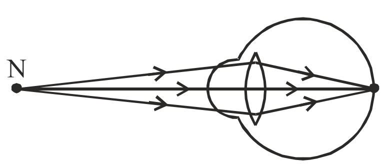
7. It is corrected by using convex lens of suitable focal length.

v = – 1 m = – 100 cm

u = – 25 cm

According to lens formula,

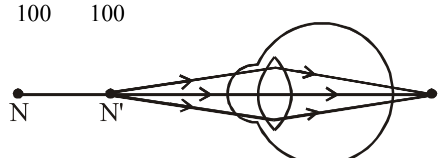
$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$



(a) Near point of a Hypermetropic eye

$\frac{1}{f} = -\frac{1}{100} - \frac{1}{-25} = -\frac{1}{100} + \frac{1}{25}$

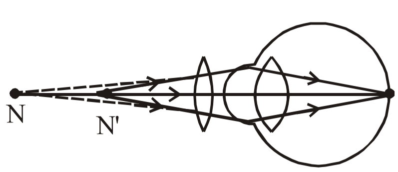
$\frac{1}{f} = \frac{-1+4}{100} = \frac{3}{100}$



(b) Hypermetropic eye

$f = \frac{100}{3} \text{cm}$

$P = \frac{1}{f} = \frac{3 \times 100}{100} = 3\text{D}$



(c) Correction for Hypermetropic eye

8. The rays coming from the objects which are at a distance less than 25 cm are not properly focussed at retina because the ciliary muscles cannot be contracted beyond this limit, so as to decrease the focal length of the eye lens.

9. The image distance remains unchanged. It is because, as distance of object increases the focal length of eye lens is adjusted by ciliary muscles such that image is always formed at retina.

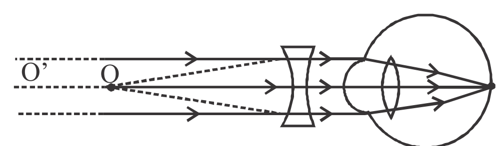
10. Planets are much closer to earth as compared to stars. They are extended source of light. They behave like a number of point sources so that the average variation is zero. Thus, planets do not twinkle.

11. In the morning, the sun is nearer to the horizon. Blue light have shorter wavelength, so , it scatters more. Therefore the red light which have longer wavelength reaches upto the eye of observer and the sun appears reddish.

12. There is nearly no atmosphere for the astronauts as they are flying high in sky. So there is no scattering of light. This is why the sky appear dark to the astronauts.

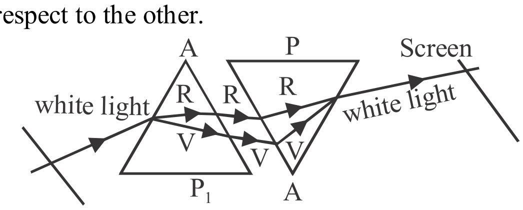
Exemplar Questions :

1. The student is suffering from myopia (near sightedness). Doctor advises her to use a concave lens of appropriate power to correct this defect.



Correction for myopia

2. By using two identical prisms, one placed inverted with respect to the other.



3. No. light from stars undergoes atmospheric refraction which occurs in medium of gradually changing refractive index.

4. Planets do not twinkle as they are closer to earth and are seen as extended sources.

Hots Questions :

1. In normal eye, the far point is infinity. The lens used should be such that an object at infinity forms virtual image at 1.2 m.

Now, $v = -1.2$ m; $v = -\infty, f = ?$

We know $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

or $\frac{1}{f} = \frac{1}{-1.2} - \frac{1}{(-\infty)} = -\frac{1}{1.2}$ or $f = -1.2$ m

Power, $P = \frac{1}{f} = \frac{1}{-1.2} = \frac{-5}{6} = -0.83\ D$

A concave (or divergent) lens of focal length 1.2 m and power – 0.83 D should be used to restore proper vision.

2. This person is hypermetropic

So, his $u = -30$ cm, $v = -1.5$ m $= -150$ cm

Focal length of corrective lens :

$$\frac{1}{f}=\frac{1}{v}-\frac{1}{u} \Rightarrow \frac{1}{f}=\frac{1}{-150}-\frac{1}{-30} \Rightarrow \frac{1}{f}=\frac{-1}{150}+\frac{1}{30}$$

$$\Rightarrow \frac{1}{f}=\frac{-1+5}{150}=\frac{4}{150} \Rightarrow f=\frac{150}{4}=+37.5 \text{ cm}$$

+ sign shows that he needs a convex lens of focal length 37.5 cm.

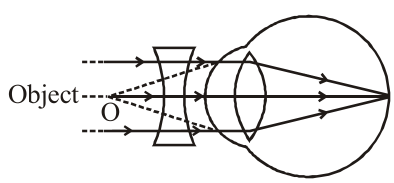
$$\therefore \text{Power of lens (P)} = \frac{100}{37.5} = 2.67 \text{ D}$$

3. (a) Myopia or near-sightedness has been shown in the figure.

(b) The points O and I represent the far point and the retina respectively.

(c) A concave lens of proper focal length is used to correct this defect.

(d)



Correctness for myopia

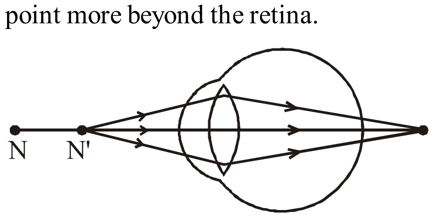
4. (a) Hypermetropia or long-sightedness has been corrected.

(b) The point represent the near point of the hypermetropic eye.

(c) In a hypermetropic eye, the rays of light coming from a near object don't converge in appropriate way so as to focus at retina but they get focussed beyond the retina. When a convex lens is used before the eye, extra focussing power is provided and the rays are focussed at the retina.

If a concave lens, on the other hand, will be used then it will diverge the rays and they will get focussed at a point more beyond the retina.

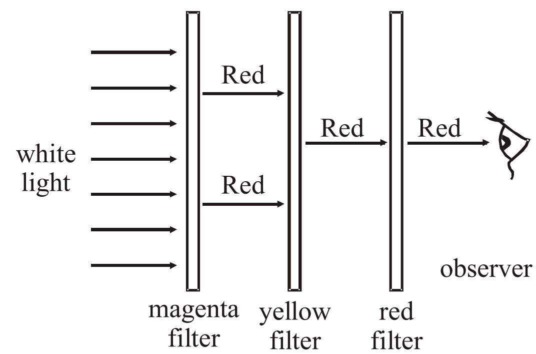
(d)



Hypermetropic eye

5. The area seen clearly with one eye is comparatively less than that seen with two eyes. Further two eyes give better judgement of distances of distant objects than one eye only. Also, left eye sees more portion of the right side of the object and the right eye sees more of the left side. Thus, two eyes do not form exactly similar images and the fusion of these two dissimilar images in the brain gives the three dimensional or the stereoscopic vision.

6.



7. Presbyopia is a defect only for near vision due to insufficient power of accommodation arising out of the inability of the ciliary muscles to squeeze the crystalline lens beyond a particular power i.e., to the full extent as in a normal defectless eye, so the near point is beyond 25 cm, whereas the far point in the relaxed condition of the eye is at infinity.

In a hypermetropic eye the crystalline lens has become less powerful (in the relaxed condition) and so it has to exercise power of accommodation to see infinitely distant objects also straining the ciliary muscles. Hypermetropia is the defect for near vision.

3 EXERCISE

Single Option Correct :

1. (d) **2.** (c) **3.** (c) **4.** (d) **5.** (a)

6. (d) **7.** (d)

8. (b) The incident angle is 45° incident angle > critical angle, $i > i_c$

$\therefore \sin i > \sin i_c$ or $\sin 45 > \sin i_c$

$\sin i_c = \frac{1}{n}$ $\quad \therefore \sin 45° > \frac{1}{n}$ or $\frac{1}{\sqrt{2}} > \frac{1}{n}$

$\Rightarrow n > \sqrt{2}$

9. (b) **10.** (c)

11. (a) Dispersion arises because of basic phenomenon refraction.

12. (d) **13.** (a) **14.** (a) **15.** (b) **16.** (c)

17. (b) **18.** (b) **19.** (d) **20.** (c) **21.** (d)

22. (b) **23.** (c) **24.** (b) **25.** (d) **26.** (a)

27.	(c)	**28.**	(b)	**29.**	(b)	**30.**	(c)	**31.**	(b)
32.	(a)	**33.**	(a)	**34.**	(c)	**35.**	(c)	**36.**	(c)
37.	(d)	**38.**	(d)	**39.**	(d)	**40.**	(a)	**41.**	(b)
42.	(b)	**43.**	(a)	**44.**	(c)	**45.**	(d)	**46.**	(a)
47.	(a)	**48.**	(a)	**49.**	(b)	**50.**	(c)	**51.**	(a)
52.	(b)	**53.**	(a)						

54. (a) Difference in refractive indices of blue and green colour are less so they are seen together and red is seen separate because deviation depends on refractive index.

55.	(c)	**56.**	(c)	**57.**	(c)	**58.**	(a)	**59.**	(b)
60.	(c)	**61.**	(c)	**62.**	(a)	**63.**	(b)	**64.**	(c)
65.	(a)	**66.**	(b)	**67.**	(b)	**68.**	(c)		

More Than One Option Correct :

1.	(a,c,d)	**2.**	(a,b,d)	**3.**	(b,c,d)
4.	(a,b,c)	**5.**	(b)	**6.**	(a,c,d)
7.	(a.b,c)	**8.**	(b,c)	**9.**	(all)
10.	(b,c,d)	**11.**	(a,b,c)	**12.**	(a,b,d)

Passage Based Questions :

1. (b) **2.** (b) **3.** (d) **4.** (c)
5. (d) **6.** (b)

7. (b) $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$

Here v = 2.5 (Distance of retina as position of image is fixed)

$u = -x$

$$\frac{1}{f}=\frac{1}{2.5}+\frac{1}{x}$$

For f_{min} : x is minimum $\frac{1}{f_{min}}=\frac{1}{2.5}+\frac{1}{25}$

For f_{max} : x is maximum $\frac{1}{f_{max}}=\frac{1}{2.5}+\frac{1}{\infty}$

For near sighted man lens should make the image of the object within 100 cm range

For lens $u = -\infty$, $v = -100$

$$\frac{1}{f_{lens}}=\frac{1}{-100}-\frac{1}{-\infty}$$

Assertion & Reason :

1. (b) In myopic eye due to the increased converging power of eye lens, the image of a far off object is formed in front of the retina.

2. (b)

3. (c) The image formed on retina is real and inverted. If magnification is less than 1, then diminished image is formed not inverted.

4. (b)

Multiple Matching Questions :

1. (a)

Integer/ Numeric Questions :

1. $P = 20\ D,\ f=\frac{1}{20}=0.05\text{ m}$

$$m=1-\frac{v}{f};\ v=-20\text{ cm}=0.2\text{ m}$$

$$\therefore\ m=1+\frac{0.2}{0.05}=1+4=5$$

2. The lens to be used is a convex lens of suitable focal length.

Here, $u = -25$ cm, $v = -1.5$ m $= -150$ cm, f = ?, P = ?

By lens formula,

$$\frac{1}{f}=\frac{1}{v}-\frac{1}{u}=\frac{1}{-150}+\frac{1}{25}=\frac{-1+6}{150}=\frac{5}{150}=\frac{1}{30}$$

$$\therefore f=+30\text{ cm}=0.3\text{ m}$$

$$\text{Power }(P)=\frac{1}{f\text{ (in m)}}=\frac{1}{0.3}=\frac{10}{3}=+3.33\text{ D.}$$

3. Here, $f = -25$ cm $\quad$ ($\because$ Lens is concave)

$$=-\frac{25}{100}\text{ m}=-\frac{1}{4}\text{ m}$$

$$\text{Power }(P)=\frac{1}{f\text{ (in m)}}=-\frac{1}{\left(\frac{1}{4}\right)}=-4\text{ D.}$$

4. Here, $f = +25$ cm $\quad$ ($\because$ Lens is convex)

$$=\frac{25}{100}\text{ m}=\frac{1}{4}\text{m}$$

$$\text{Power }(P)=\frac{1}{f\text{(in m)}}=\frac{1}{\left(\frac{1}{4}\right)}=+4\text{ D.}$$

5. Here, $P = -0.6$ D.

We know that, $P=\frac{-1}{\text{Far point (in m)}}$

$$\Rightarrow\ \text{Far point}=\frac{-1}{P}=\frac{-1}{-0.6}=\frac{10}{6}=1.66\text{ m}$$

6. Here, $P = +0.8$ D

$$u=-25\text{ cm}=-\frac{25}{100}\text{ m}=-\frac{1}{4}\text{ m}$$

v = ?

We have,

$$\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$$

or, $P=\frac{1}{v}-\frac{1}{u}\quad\left(\because P=\frac{1}{f}\right)$

or, $P=\frac{1}{v}-\frac{1}{\left(-\frac{1}{4}\right)}$ or, $\frac{1}{v}=P-4$

or, $\frac{1}{v}=0.8-4$ or, $\frac{1}{v}=-3.2$

$\Rightarrow v=-\frac{1}{3.2}\text{ m}=-\frac{10}{32}\text{ m}=-0.31\text{ m}$

Therefore, near point of the eye is 0.31 m.

7. The far point of this myopic person is 80 cm. This means that this person can see the distant object (which is kept at infinity) clearly if the image of this object is formed at his far point (80 cm). Therefore, in this case,

$$u=-\infty, v=-80\ cm,\ f=?$$

Using lens formula, $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$

or $\frac{1}{-80}-\frac{1}{\infty}=\frac{1}{f}$ or $-\frac{1}{80}-0=\frac{1}{f}$

or $f=-80\text{ cm}=-0.8\text{ m}$

The negative (–) sign indicates that the lens is concave.

Now, Power $P=\frac{1}{f\ (in\ m)}=\frac{1}{-0.8}=-1.25\ D$

The concave lens of power – 1.25 D is required to correct the problem.

8. The defect of the vision is hypermetropia. The formula used is $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$

Given, $u=-25$ cm and $v=-75$ cm.

$\therefore\ \frac{1}{f}=-\frac{1}{75}+\frac{1}{25}=+\frac{2}{75}$ or $f=+\frac{75}{2}=+37.5$ cm

Power of the lens

$=\frac{1}{f\ (\text{in metres})}=\frac{100}{75/2}=+\frac{8}{3}=+2.67\ D$

9. Here, $v=-3$ m, $u=-12$ m, $f=?$

$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$ or $-\frac{1}{3}+\frac{1}{12}=\frac{1}{f}$ or $f=-4$ m

A concave lens of focal length 4 m should be used.

10. A myopic person needs a concave lens for the correction of his eyesight.

His $v=-80$ cm. (far point), $u=\infty$ (infinity)

So, $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}\Rightarrow\ \frac{1}{f}=\frac{1}{v}\ \left(\text{as } \frac{1}{\infty}=0\right)$

$\Rightarrow\ \frac{1}{f}=\frac{1}{-80}\ \Rightarrow\ f=-80\text{ cm}\ \Rightarrow f=-0.8\text{ m.}$

$\therefore\ P=\frac{1}{-0.8}=-1.25\ D$ (Dioptres)

11. From the relationship between critical angle (i_c) and refractive index (μ), we get $\sin i_c=\frac{1}{\mu}$

In the case of water, $\mu=1.33$

so, $\sin i_c=\frac{1}{1.33}$ or $i_c=48°$

But, the angle of resistance is 45° i.e. $i=45°$ and $i_c>i$. If the angle of incidence would have been greater than the critical angle, then the ray of light might not come out of water surface due to total internal reflection. But in the present situation, since the angle of incidence is less than the critical angle, the ray of light will be able to come out of the water surface.

4 ADVANCED EXERCISE
BASED ON CONNECTING TOPICS

1. (a)

2. (c) Dispersive power of prism $\omega=\left(\frac{\mu_v-\mu_r}{\mu_y-1}\right)$

but $\mu_y=\frac{\mu_v+\mu_r}{2}=\frac{1.52+1.51}{2}=1.515$

Therefore $\omega=\frac{1.52-1.51}{1.515-1}=\frac{0.1}{1.515}=0.019.$

3. (c) In case of minimum deviation, the light ray inside prism becomes parallel to base of the prism.

4. (b) $\mu=\frac{\sin(A+\delta_m)/2}{\sin 30^0}$

$\Rightarrow\ 1.414=\frac{\sin(60+\delta_m)/2}{\sin 30^0}$

$\Rightarrow\ \text{Sin}\left(\frac{60^\circ+\delta_m}{2}\right)=0.707=\sin 45^o$

$\Rightarrow\ \frac{60+\delta_m}{2}=45^o\Rightarrow\ \delta_m=30^o$

5. (c) $M=-\frac{f_0}{f_e}=-\frac{400}{10}=-40$

Angle subtended by the moon at the objective

$= \dfrac{3.5 \times 10^3}{3.8 \times 10^5} = 0.009$ radian.

Thus angular diameter of the image
$= M \times$ visual angle
$= 40 \times 0.009 = 0.36$ radian

$= \dfrac{0.36 \times 180}{3.14} = 20°$

6. (b) $m = \dfrac{f_0}{f_e} = \dfrac{\beta}{\alpha}$

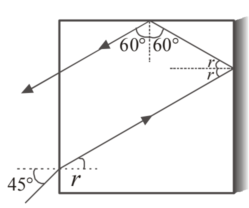
$\therefore \quad \beta = \alpha \dfrac{f_0}{f_e} = 2 \times \dfrac{60}{5} = 24°$

7. (a) **8.** (c) **9.** (a) **10.** (b) **11.** **(c)**

12. (d)

13. (d) $i = 2r$

14. (c)



From Snell's law,

$$\frac{\sin 45°}{\sin r} = \sqrt{2}$$

or $\quad \sin r = \dfrac{1}{2}$

$\therefore \quad r = 30°$

Critical angle, $\sin C = \dfrac{1}{\mu} = \dfrac{1}{\sqrt{2}}$

$\therefore \quad C = 45°$

So ray comes out antiparallel to the incident ray.

15. (b)

16. (b) Magnifying power of compound microscope is proportional to length of the microscope.

17. (c)

18. (d) R. P. $\propto$ aperture of objective lens.

19. (d) $f_o + f_e = 36$

and $\quad \dfrac{f_o}{f_e} = 5$

$\therefore \quad f_o = 6$ cm and $f_e = 30$ cm

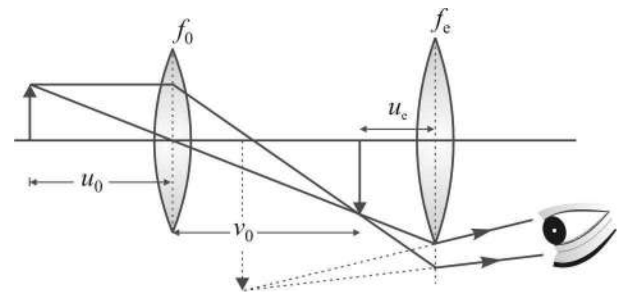
20. (d)

21. (a,b,) **22.** (a,b,c) **23.** (a, c)

24. (a, b, c, d)

25. (c), **26.** (a)

For objective lens,



$$\frac{1}{v_o} - \frac{1}{-200} = \frac{1}{+50}$$

$\therefore \quad v_o = \dfrac{200}{3}$ cm

For eyepiece,

$$\frac{1}{-25} - \frac{1}{u_e} = \frac{1}{+5}$$

$\therefore \quad u_e = \dfrac{-25}{6}$ cm

The separation between the objective and eyepiece

$L = v_o + |u_e| = \dfrac{200}{3} + \dfrac{25}{6} = 70.8$ cm

The required magnification is calculated as

$$M = M_o \times M_e,$$

where $\quad |M_o| = \dfrac{v_o}{u_o} = \dfrac{200/3}{200} = \dfrac{1}{3}$

and $\quad |M_e| = \dfrac{v_e}{u_e} = \dfrac{25}{25/6} = 6$

$\therefore \quad M = \dfrac{1}{3} \times 6 = 2$.

27. (a) Reason is correct explanation of Assertion.

28. (d)

29. (a) RP $\propto$ diameter of objective.

30. (a) A-t : The angle of deviation, $\delta = 180° - 2i = 180° - 2 \times 60° = 60°$
B-p : Glass slab produces no deviation and so $\delta = 0$.
C-q, s : Deviation in both the cases are 180°.
D-r : $\delta = 60° - 30° = 30°$

31. Dispersive power of prism

$$\omega = \left(\frac{\mu_v - \mu_r}{\mu_y - 1}\right)$$

$$\mu_y = \frac{\mu_v + \mu_r}{2} = \frac{1.52 + 1.51}{2} = 1.515$$

Therefore $\omega = \dfrac{1.52 - 1.51}{1.515 - 1} = \dfrac{0.01}{0.515} = 0.019.$

32. $\mu = \dfrac{\sin(A+\delta_m)/2}{\sin A/2}$

$\Rightarrow 1.414 = \dfrac{\sin(60° + \delta_m)/2}{\sin 30°}$

$\Rightarrow \text{Sin}\left(\dfrac{60° + \delta_m}{2}\right) = 0.707 = \sin 45^o$

$\Rightarrow \dfrac{60+\delta_m}{2} = 45^o \Rightarrow \delta_m = 30^o$

33. For a direct vision spectroscope

$\delta_1 + \delta_2 = 0$

$\therefore \quad (\mu_1 - 1)A_1 + (\mu_2 - 1)A_2 = 0$

or, $\quad A_2 = -\left(\dfrac{\mu_1 - 1}{\mu_2 - 1}\right)A_1 = -\left(\dfrac{1.52-1}{1.63-1}\right) \times 5^o = -4.12^o$

34. Length of microscope

$L = v_0 + f_e$ or $14 = v_0 + 5 \Rightarrow v_0 = 9$ cm

Now, $M = -\dfrac{v_0}{u_0} \times \dfrac{D}{f_e}$, or $\quad 25 = -\dfrac{9}{u_0} \times \dfrac{25}{5}$

or, $\quad u_0 = -\dfrac{9}{5} = -1.8$ cm

Now, $\dfrac{1}{f_0} = \dfrac{1}{v_0} - \dfrac{1}{u_0}$ but u_0 is negative.

Therefore $\dfrac{1}{f_0} = \dfrac{1}{9} + \dfrac{5}{9} = \dfrac{6}{9}$ or $f_0 = 1.5$ cm

35. $M = -\dfrac{f_0}{f_e} = -\dfrac{400}{10} = -40$

Angle subtended by the moon at the objective

$= \dfrac{3.5 \times 10^3}{3.8 \times 10^5} = 0.009$ radian.

Thus angular diameter of the image

$= M \times$ visual angle

$= 40 \times 0.009 = 0.36$ radian

$= \dfrac{0.36 \times 180}{3.14} = 20°$

Chapter 3

ELECTRICITY

INTRODUCTION

Electricity is the branch of physics in which we study electric charges, at rest (electrostatics or static electricity) and in motion (current electricity).

When we switch on the bulb of our rooms, it glows immediately. An electric signal in a conductor travels at a speed of light in vacuum i.e., $c = 3 \times 10^8$ m/s. When we connect our room heater to the 'pins' placed on the walls, it produces heat. When we provide 'cells' to our torch and press its button, it glows and produces light. All of these phenomena are based on the subject matter of this chapter.

Moving charges produce electric current. Electric current produces many effects like heating effect, chemical effect, magnetic effect, etc. This chapter provides us a strong base on how electric current is produced, which instruments are used for electrical measurement, the factors affecting electric current, etc. The chapter also deals with the factor which resists the flow of electric current known as 'electrical resistance'.

We use electric iron to press our clothes, room heater to get rid of cold, electrical lamps to lit our rooms, etc. We access these facilities due to heating effect of current. In these phenomena, electrical energy is converted into heat energy.

ELECTRIC CURRENT

We define the electric current, or simply the current, to be *the net amount of charges passing per unit time across any section through a conductor*. If the charges are positive, the current is assumed to flow in the direction of charges and if the charges are negative, the current is in a direction opposite to the charges.

If ΔQ is the amount of charge that passes through a particular area in a time interval Δt, the average current, I_{av}, is equal to the ratio of the charge to the time interval.

i.e., $$I_{av} = \frac{\Delta Q}{\Delta t}$$

The ***SI* unit** of current is ampere (A), where $1A = 1\ C/s$

That is, $1A$ of current is equivalent to $1C$ of charge passing through the surface in $1s$.

In practice, smaller units of current are often used, such as the milliampere (1mA = 10^{-3} A) and the microampere ($1\mu A = 10^{-6}\ A$).

In a conductor such as copper, the current is due to the motion of the negatively charged electrons. Therefore, when we speak of current in an ordinary conductor, such as a copper wire, the direction of the current will be opposite to the direction of flow of electrons.

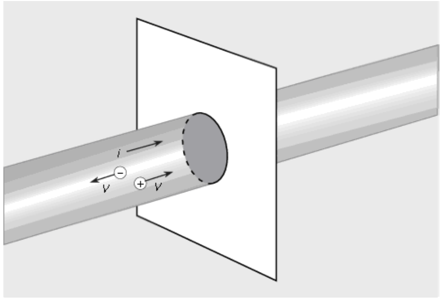


Fig. 3.1

If the charge on an electron is e and n (n = 1, 2, 3 .... integer) electrons pass through a point in time t then the total charge passing through that point will be $Q = ne$ **(quantization of charge)**.

Therefore, the current $I = \dfrac{ne}{t}$ where $e = 1.6 \times 10^{-19}$ coulomb.

CONVENTIONAL AND ELECTRON FLOW NOTATION

When Benjamin Franklin made his conjecture regarding the direction of charge flow (from the smooth wax to the rough wool), he set a precedent for electrical notation that exists to this day, despite the fact that we know electrons are the constituent units of charge, and that they are displaced from the wool to the wax -- not from the wax to the wool -- when those two substances are rubbed together. This is why electrons are said to have a negative charge: because Franklin assumed electric charge moved in the opposite direction that it actually does, and so objects he called "negative" (representing a deficiency of charge) actually have a surplus of electrons.

By the time the true direction of electron flow was discovered, the nomenclature of "positive" and "negative" had already been so well established in the scientific community that no effort was made to change it, although calling electrons "positive" would make more sense in referring to "excess" charge. You see, the terms "positive" and "negative" are human inventions, and as such have no absolute meaning beyond our own conventions of language and scientific description. Franklin could have just as easily referred to a surplus of charge as "black" and a deficiency as "white," in which case scientists would speak of electrons having a "white" charge (assuming the same incorrect conjecture of charge position between wax and wool).

However, because we tend to associate the word "positive" with "surplus" and "negative" with "deficiency," the standard label for electron charge does seem backward. Because of this, many engineers decided to retain the old concept of electricity with "positive" referring to a surplus of charge, and label charge flow (current) accordingly.

This is known as **conventional flow notation**.

Others chose to designate charge flow according to the actual motion of electrons in a circuit. This form of symbology is known as **electron flow notation**:

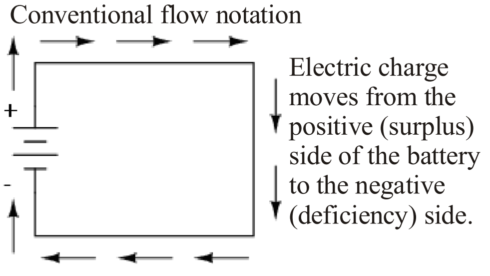


Fig. 3.2 (a)

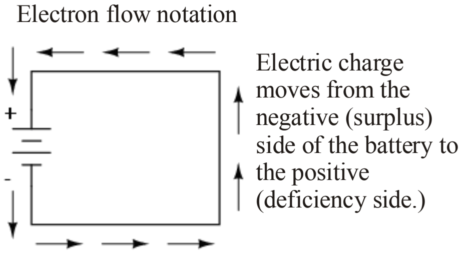


Fig. 3.2 (b)

In conventional flow notation, we show the motion of charge according to the (technically incorrect) labels of + and –. This way the labels make sense, but the direction of charge flow is incorrect. In electron flow notation, we follow the actual motion of electrons in the circuit, but the + and – labels seem backward. Does it matter, really, how we designate charge flow in a circuit? Not really, so long as we're consistent in the use of our symbols. You may follow an imagined direction of current (conventional flow) or the actual (electron flow) with equal success insofar as circuit analysis is concerned.

The current may be constituted by motion of different type of charge carriers in different situations.

S.No.	Nature of material	Cause of current
1.	Conductors	Motion of electrons
2.	Vacuum tubes	Motion of electrons
3.	Semiconductors	Motion of holes and electrons
4.	Electrolytes	Motion of positive and negative ions
5.	Discharge tube	Motion of positive and negative ions

Types of Current

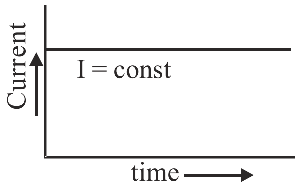


Fig. 3.3 (a)

(a) Direct current : The current whose magnitude and direction does not vary with time is called direct current (dc). The various sources are cells, battery, dc dynamo etc.

(b) Alternating current : The current whose magnitude continuously changes with time and periodically changes its direction is called alternating current. It has constant amplitude and has alternate positive and negative halves. It is produced by ac dynamo.

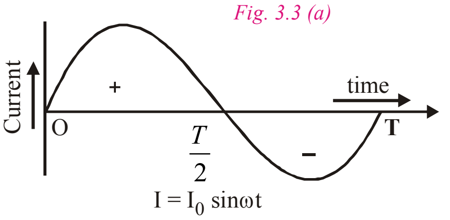


Fig. 3.3 (b)

ILLUSTRATION : 3.1

If a current 3.2 ampere per second flows through a conducting wire, calculate the number of electrons passing through the wire.

SOLUTION :

Here, $I = 3.2A$, $t = 1$ second, $n = ?$,

As we know, $I = \frac{ne}{t}$; $3.2 = \frac{n\times1.6\times10^{-19}}{1}$ [$\because$ $e = 1.6 \times 10^{-19}$ coulomb]

or $n \times 1.6 \times 10^{-19} = 3.2$ or $n = \frac{3.2}{1.6\times10^{-19}} = 2 \times 10^{19}$ electrons

ILLUSTRATION : 3.2

If 25 coulomb charge flow in a conductor in 5 seconds then find out the value of electric current in it.

SOLUTION :

Here, $Q = 25$ coulomb, $t = 5$ second, $I = ?$

Electric current $I = \frac{Q}{t} = \frac{25}{5} = 5$ ampere

ILLUSTRATION : 3.3

If a light bulb uses 0.50 ampere of current, how much charge flows through it in 5 minutes ?

SOLUTION :

Five minutes = 300 seconds, so from

$$\Delta q = I\Delta t$$

$$\Delta q = (0.50A)\,(300s) = 150C$$

ELECTRIC POTENTIAL

Electric potential at a point in electric field is defined to be equal to *the minimum work done by an external agent in moving a unit positive charge from infinity or a reference point to that point against the electrical force of the field*.

Electric potential at a point in electric field is numerically equal but opposite in sign to the work performed by electrical force to bring unit positive charge from infinity to that point.

If W is the work done by external agent in bringing a positive test charge q_0 from infinity to a point then the potential V at that point,

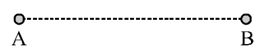
$$V = \frac{W_{\text{ext}}}{q_0} \quad ; \quad V = -\frac{W_E (\text{work done by electric field})}{q_0}$$

The **SI unit** of electric potential is joule/coulomb or volt.

ELECTRIC POTENTIAL DIFFERENCE

Potential deference between two points is equal to *the minimum work done in moving a unit positive test charge from one point to the other*.

$$V_B - V_A = \frac{W_{AB}}{q_0} \Rightarrow W_{AB} = q_0 (V_B - V_A)$$



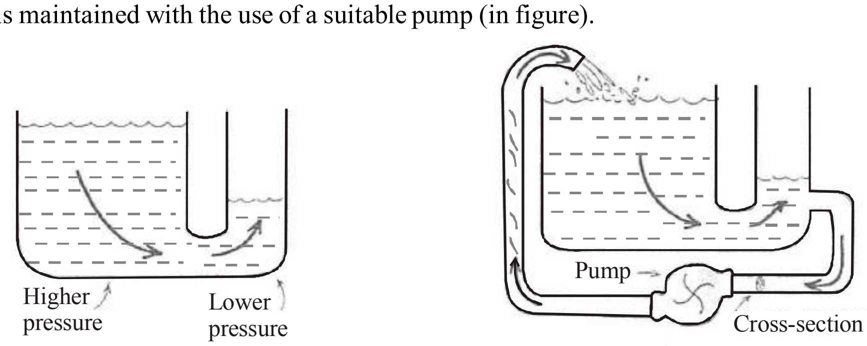
W_E is the work done by the electric field then ;

$$-(V_B - V_A) = \frac{W_E}{q_0} \Rightarrow W_E = -q_0 (V_B - V_A); \; W_{\text{ext.}} = -W_E$$

UNDERSTANDING POTENTIAL DIFFERENCE

When the ends of a heat conductor are at different temperatures, heat energy flows from the higher temperature to the lower temperature. The flow ceases when both ends reach the same temperature. Similarly, when the ends of an electrical conductor are at different electric potentials – when there is a **potential difference** – charges in the conductor flow from the higher potential to the lower potential. The flow of charge persists until both ends reach the same potential. Without a potential difference, no flow of charge will occur.

To attain a sustained flow of charge in a conductor, some arrangement must be provided to maintain a difference in potential while charge flows from one end to the other. The situation is analogous to the flow of water from a higher reservoir to a lower one fig. Water will flow in a pipe that connects the reservoirs only as long as a difference in water level exists. The flow of water in the pipe, like the flow of charge in a wire, will cease when the pressures at each end are equal. (We imply this phenomenon when we say that water seeks its own level.) A continuous flow is possible if the difference in water levels – hence the difference in water pressures – is maintained with the use of a suitable pump (in figure).



(a) Water flows from the reservoir of higher pressure to the reservoir of lower pressure. The flow will cease when the difference in pressure ceases.

(b) Water continue to flow because a difference in pressure is maintained with the pump.

Fig. 3.4

A sustained electric current requires a suitable pumping device to maintain a difference in electric potential – to maintain a voltage. Batteries or generators are "electrical pumps" that can maintain a steady flow of charge. These devices do work to pull negative charges apart from positive ones. In chemical batteries, this work is done by the chemical disintegration of zinc or lead in acid, and the energy stored in the chemical bonds is converted to electric potential energy.

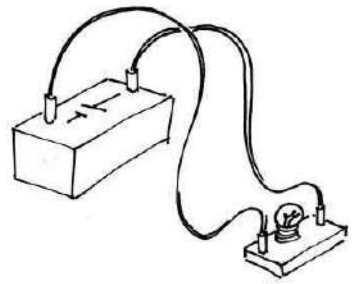


Fig.3.5 Each coulomb of charge that is made to flow in a circuit that connects the ends of this 1.5V. Flashlight cell is energized with 1.5J.

Generators separate charge by electromagnetic induction, a process we will describe in the next chapter. The work that is done (by whatever means) in separating the opposite charges is available at the terminals of the battery or generator. This energy per charge provides the difference in potential (voltage) that provides the "electrical pressure" to move electrons through a circuit joined to those terminals.

A common automobile battery will provide an electrical pressure of 12 volts to a circuit connected across its terminals. Then 12 joules of energy are supplied to each coulomb of charge that is made to flow in the circuit.

CHECK *Point*

If a current of one-or two-tenths of an ampere were to flow into one of your hands and out the other, you would probably be electrocuted. But, if the same current were to flow into your hand and out the elbow above the same hand, you could survive, even though the current might be large enough to burn your flesh. Explain.

SOLUTION

If a current of one-or-two-tenths of an ampere flows into one of our hands and out the other, we may be electrocuted, probably, because the electric circuit formed becomes closed. But when the same current flows into the hand and out the elbow above the same hand, the electric circuit is not completed, and we could survive.

ILLUSTRATION : 3.4

Ten positively charged particles have the charges 1×10^{-8} *C*, 4×10^{-8} *C*, 9×10^{-8} *C*, 16×10^{-8} *C* ...., 100×10^{-8} *C* and are situated on the *x*-axis at the points $x = 0.1$ m, 0.2 m, 0.3 m, ..., 1.0 m, respectively. Calculate the electric potential at the origin *O*.

SOLUTION :

The electric potential at the origin *O* due to the given ten positively-charged particles

0   1×10^{-8} C 4×10^{-8}C 9×10^{-8} 16×10^{-8}

$x = 0$ 0.1m   0.2m   0.3m   0.4m

$$V = (9 \times 10^9) \times \left[\frac{1\times10^{-8}}{0.1} + \frac{4\times10^{-8}}{0.2} + \frac{9\times10^{-8}}{0.3} + ... + \frac{100\times10^{-8}}{10}\right] \left[\because V = K,\left(\frac{q_1}{l_1} + \frac{q_2}{l_2} ... \frac{q_n}{l_n}\right)\right]$$

$= 90 \times [10 + 20 + 30 + ... + 100] = 900 \times [1 + 2 + 3 + ... + 10]$

$= 900 \times 55 = 4.95 \times 10^4$ volt.

ILLUSTRATION : 3.5

A uniform electric field of 10 N/C exists in the vertically downward direction. Find the increase in the electric potential as we go up through a height of 0.5 m.

SOLUTION :

The increase in the electric potential $(V_B - V_A)$ as we go up from the point *A* to the point *B* through a height of 0.5 m is equal to the work done in displacing a charge of + 1*C* from *A* to *B* against the electric field. Therefore, we have

$$\Delta V = (V_B - V_A) = +10\frac{N}{C} \times 1C \times 0.5\text{m} = 5V$$

ELECTRIC CIRCUIT AND CIRCUIT DIAGRAM

A continuous and closed path of an electric current is called electric circuit.

An arrangement of various electric components used in electric circuit with the help of their electrical symbols is called **circuit diagram.** A circuit diagram in which a cell, a rheostat a switch, an ammeter, a voltmeter, and a resistor are connected by connecting wires is shown in figure.

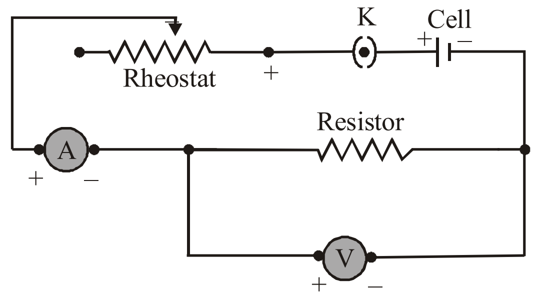


Fig. 3.6 : Simple circuit diagram

Some commonly used electric components

1. **Cell :** Direct current source of electromotive force. Combination of two or more cells is called **battery**.

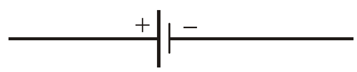


Fig. 3.7 Symbol of cell p = 16

2. **Rheostat (variable resistance) :** Wire of special type of alloy like manganin, eureka, nichrome etc. is wound on a hollow cylinder of china clay. It controls the current in the electric circuit.

(a) **(b)**

Fig. 3.8

3. **Switch :** It is used to close or open the electric circuit, controls the movement of electrons in a circuit.

Symbol of switch or plug key

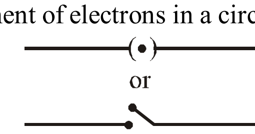


Fig. 3.9

4. **Ammeter :** Measures the value of current flowing in the circuit. The resistance of ammeter is small and it is used in series with the circuit.

(a) **(b)**

Fig. 3.11

5. **Voltmeter :** Measures the potential difference between two points in the circuit. Its resistance is high and it is used in parallel with the resistance wire.

(a) **(b)**

Fig. 3.11

CHECK Point

One example of a water system is a garden hose that waters a garden. Another is the cooling system of an automobile. Which of these exhibits behavior more analogous to that of an electric circuit? Why?

SOLUTION

The garden hose is more analogous to an electric circuit as it contains a source of water in which there is a pressure difference like an electric circuit contains a source of electrical energy which has a potential difference. Also, the water is supplied through a pipe in the same way as a conducting path is provided for the flow of electrical energy in a circuit.

ELECTRICAL RESISTANCE

Directly connecting the poles of a voltage source together with a single piece of wire is dangerous because the magnitude of electric current may be very large in such a short circuit, and the release of energy very dramatic (usually in the form of heat),you may have heard about firing due to short circuit. Usually, electric circuits are constructed in such a way as to make practical use of that released energy, in as safe a manner as possible. One practical and popular use of electric current is for the operation of electric lighting. The simplest form of electric lamp is a tiny metal "filament" inside of a clear glass bulb, which glows white-hot (incandesces) with heat energy when sufficient electric current passes through it. Like the battery, it has two conductive connection points, one for electrons to enter and the other for electrons to exit. Connected to a source of voltage, an electric lamp circuit looks something like this:

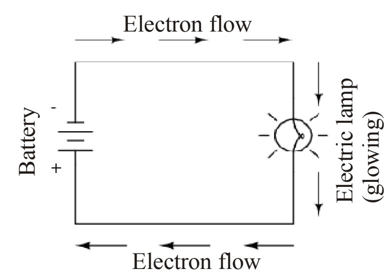


Fig. 3.12

As the electrons work their way through the thin metal filament of the lamp, they encounter more opposition to motion than they typically would in a thick piece of wire. This opposition to electric current depends on the type of material, its cross-sectional area, and its temperature. It is technically known as resistance.

Resistance is the obstruction offered to the flow of electric current. (It can be said that conductors have low resistance and insulators have very high resistance.) This resistance serves to limit the amount of current through the circuit with a given amount of voltage supplied by the battery, as compared with the "short circuit" where we had nothing but a wire joining one end of the voltage source (battery) to the other.

The **S.I. unit** of resistance is ohm (Ω).

The reciprocal of resistance is called conductance G = 1/R

Its **S.I. unit** is ohm^{-1} or mho or siemen (s).

When electrons move against the opposition of resistance, due to friction heat is generated. Just like mechanical friction, the friction produced by electrons flowing against a resistance manifests itself in the form of heat. The concentrated resistance of a lamp's filament results in a relatively large amount of heat energy dissipated at that filament. This heat energy is enough to cause the filament to glow white-hot, producing light, whereas the wires connecting the lamp to the battery (which have much lower resistance) hardly even get warm while conducting the same amount of current. How to deal with resistance mathematically? You will find the answer in Ohm's law section.

FACTORS AFFECTING RESISTANCE

The resistance of a conductor depends on *temperature*, *nature* of *material*, *length* and *area* of *cross-section*.

Resistance depends on temperature:

If the resistance of the wire at 0°C be R_0 and at t°C be R_t, then the value of R_t is obtained by the following formula

$$R_t = R_0 (1 + \alpha t) \quad .... (1)$$

where α is a constant which is called the **'temperature coefficient of resistance'** of the material of the wire.

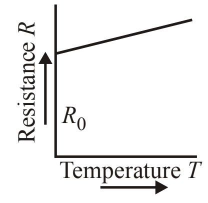


Fig. 3.13

From eq. (1), we have $$\alpha = \frac{R_t - R_0}{R_0 \times t} \text{ per } °C$$

If R_0 = 1 ohm, t = 1°C then α = (R_t – R_0) = increase in resistance.

Therefore, if the resistance of a wire at 0°C be 1 ohm, then on raising its temperature to 1°C, the increase in its resistance will be equal to the "temperature coefficient of resistance' of the material of that wire. For most of the metals, the value of α is nearly (1/273) per °C. Hence, by eq. (1), we have

$$R_t = R_0\left(1+\frac{t}{273}\right) = R_0\frac{(273+t)}{273} = R_0\left(\frac{T}{273}\right)$$

where T is the absolute temperature. Thus, $R_t \propto T$

Thus, the resistance of a pure metallic wire is directly proportional to its absolute temperature.

The resistivity of alloys also increases with rise in temperature, but this increase is much smaller compared to pure metals.

There are certain alloys such as manganin, constantan, nichrome, etc., whose resistivity is little affected by temperature, that is, their temperature coefficient of resistance is negligible. On account of their high resistivity and negligible temperature coefficient of resistance, these alloys are used to make wires for standard resistances, resistance boxes, etc.

Resistance depends on the length and the cross-section of the wire :

The resistance of ohmic circuit elements such as metal wires or carbon resistor depends on their geometries.

To find dependence, first we will keep the thickness of the object (like a copper wire) fixed and just increase or decrease the length of the wire. If we apply a potential difference across the ends of the wire and use current and potential difference measurements, we can determine its resistance as a function of length. We find that *there is a proportionality between the length L of the wire and the resistance of the wire R*. Thus we can write

$$R \propto L$$

i.e., $$R = kL$$

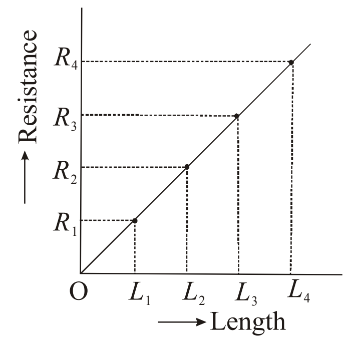


Fig. 3.14 (a)

If instead we fix the length of the copper wire and vary the thickness or cross-sectional area A then we find the resistance of the copper decreases as the cross-sectional area A of the wire increases.

In fact we get an inverse relationship so that $R \propto \frac{1}{A}$ or, $R = k'\frac{1}{A}$

Combining these two expressions gives us : $R = kk'\frac{L}{A}$

To simplify this expression, we can replace the product of the two constants with a single new constant and write $R = \rho\frac{L}{A}$

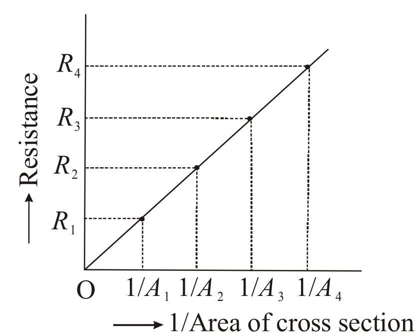


Fig. 3.14 (b)

Where ρ is a constant, which is called the **specific resistance** or **resistivity of the conducting material**. It does not depend on the area of cross-section. *Resistivity depends only on the nature of material and temperature*.

Resistivity, $\rho = R\frac{A}{L}$ $\therefore$ The **SI unit of** $\rho = \frac{\text{ohm}\times\text{m}^2}{\text{m}} = \text{ohm}\times\text{meter } (\Omega\text{m})$

Definition of resistivity : If $L = 1$ meter, $A = 1$ square meter then $\rho = R$ (numerically) i.e. resistance of a wire of unit length and unit area of cross section is numerically equal to the resistivity or specific resistance of the material of wire.

Remember resistance is a property of an object. Resistivity is a property of a material.

Resistance of some metallic conductors rises with increase in temperature, e.g. copper, silver etc. Resistance of some alloys such as manganin and constantan changes very slowly with increase in temperature. Contrary to this, resistance of semiconductors such as germanium (Ge), silicon (Si) etc. decreases with increase in temperature.

On decreasing temperature of some metals, the resistance becomes zero at a certain temperature.

For example : Resistance of mercury becomes zero at 4.2 K temperature.

ACTIVITY : To show dependence of resistance on length, area of cross-section and material of the conducting material

Complete an electric circuit consisting of a cell, an ammeter, a nichrome wire of length l [say, marked (1)] and a plug key, as shown in fig. 3.15. Now, plug the key. Note the current in the ammeter.

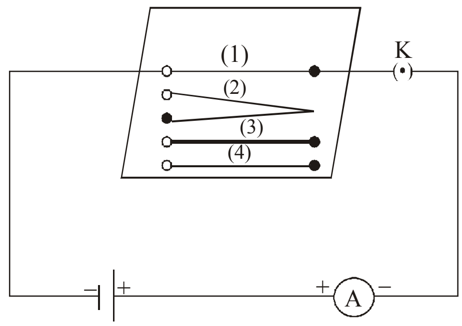


Fig. 3.15 : Electric circuit to study the factors on which the resistance of conducting wires depends.

Replace the nichrome wire by another nichrome wire of same thickness but twice the length, that is $2l$ [marked (2) in the Fig]. Note the ammeter reading.
Now replace the wire by a thicker nichrome wire, of the same length l [marked (3)]. A thicker wire has a larger cross-sectional area. Again note down the current through the circuit.
Instead of taking a nichrome wire, connect a copper wire [marked (4) in Fig.] in the circuit. Let the wire be of the same length and same area of cross-section as that of the first nichrome wire [marked (1)]. Note the value of the current.
Notice the difference in the current in all cases.
Does the current depend on the length of the conductor?
Does the current depend on the area of cross-section of the wire used?
Does the current depend on the area of cross-section of the wire used?

Knowledge ENHANCER

If a wire is stretched such that length becomes n times, resistance becomes n^2 times. Due to stretching, the cross-sectional area decreases to n times and volume (or mass) remains constant.

Volume (V) = $A\ell$,

$$A\ell = A'n\ell$$

New cross-sectional area $A' = \dfrac{A}{n}$

New resistance $R' = \dfrac{\rho n\ell}{A/n} = \dfrac{n^2\rho\ell}{A} = n^2 R$

The fractional change in resistance without change in volume or mass are :

(a) When change in length (L) is small (≤ 5%) fractional change in R is $\dfrac{\Delta R}{R} = \dfrac{2\Delta L}{L}$

(b) When change in radius (r) is small (≤ 5%) fractional change in R is $\dfrac{\Delta R}{R} = \dfrac{-4\Delta r}{r}$

(c) When change in area A is small (≤ 5%) fractional change in R is $\dfrac{\Delta R}{R} = \dfrac{-2\Delta A}{A}$

CHECK Point

Choose the correct alternative

(a) Alloys of metals usually have (greater/less) resistivity than that of their constituent metals.
(b) Alloys usually have much (lower/higher) temperature coefficients of resistance than pure metals.
(c) The resistance of graphite and most non-metals increases/decreases with increase in temperature.
(d) The resistivity of a semiconductor increases/decreases rapidly with increasing temperature.
(e) The resistivity of the alloy manganin is nearly independent of/increases rapidly with increases of temperature.
(f) The resistivity of a typical insulator (e.g., amber) is greater than that of a metal by a factor of the order of ($10^{22}/10^{23}$)

SOLUTION

(a) Alloys of metals usually have *greater* resistivity than that of their constituent metals.
(b) Alloys usually have much *lower* temperature coefficients of resistance than pure metals.
(c) The resistance of graphite and most non metals *decreases* with increase in temperature.
(d) The resistivity of a semiconductor *decreases* rapidly with increasing temperature.
(e) The resistivity of the alloy manganin is *nearly independent* of increasing temperature.
(f) The resistivity of a typical insulator (e.g. amber) is greater than that of a metal by factor of the order of 10^{22}.

ILLUSTRATION : 3.6

The resistivity of copper at room temperature is 1.72×10^{-6} ohm-centimeter. What is the resistance of a copper wire 35 meters long and 0.025 centimeter in cross section?

SOLUTION :

Given: $\rho = 1.72 \times 10^{-6}\ \Omega$ cm, $l = 35$m, A = 0.025 cm^2

Resistance, $R = \frac{\rho\ell}{A} = \frac{(1.72\times10^{-6}\,\Omega\text{ cm})\,(3500\text{ cm})}{0.025\text{ cm}^2} = 0.24\ \Omega$

ILLUSTRATION : 3.7

The resistance of a wire of length 100 cm and of uniform area of cross-section 0.020 cm^2, is found to be 2.0 ohm. Calculate specific resistance of wire.

SOLUTION :

Here, $\ell = 100$ cm, $A = 0.020$ cm^2, $R = 2.0\ \Omega$

Specific resistance $\rho = \frac{RA}{\ell} = \frac{2.0\times0.020}{100} = 0.0004\ \Omega$ cm

ILLUSTRATION : 3.8

What length of wire of resistivity $100 \times 10^{-8}\ \Omega$m, area of cross-section 2.5×10^{-7} m^2, would be needed to make a resistor of 57.6Ω?

SOLUTION :

Here, $R = 57.6\Omega,\ A = 2.5\times10^{-7}\ m^2,\ \rho = 100\times10^{-8}\ \Omega\text{m},\ l = ?$

As we know, $R = \frac{\rho l}{A}$ so, $l = \frac{RA}{\rho} \Rightarrow l = \frac{57.6\times2.5\times10^{-7}}{100\times10^{-8}}\frac{\text{m}^2}{\text{m}} = 1.44$ m

ILLUSTRATION : 3.9

Two wires *A* and *B* of equal masses and of same metal are taken. The diameter of the wire *A* is half the diameter of the wire *B*. If the resistance of the wire *A* be 24 ohm, calculate the resistance of the wire *B*.

SOLUTION :

Let r_A be the radius and ℓ_A the length of the wire *A*, and r_B the radius and ℓ_B the length of the wire *B*. Both the wires are of the same material (density *d*). Since the masses of the two wires are equal, we have

$$\pi r_A^2\ell_A\times d = \pi r_B^2\ell_B\times d$$

$$\therefore \quad \frac{\ell_A}{\ell_B} = \frac{r_B^2}{r_A^2} \quad \text{.......... (1)}$$

Resistance of the wire *A* is $R_A = \rho\frac{\ell_A}{\pi r_A^2}$, Resistance of the wire *B* is $R_B = \rho\frac{\ell_B}{\pi r_B^2}$

where ρ is the specific resistance of the material of the wires

$$\therefore \quad \frac{R_A}{R_B} = \frac{\ell_A}{\ell_B}\times\frac{r_B^2}{r_A^2} = \frac{r_B^4}{r_A^4}$$

But $r_A = \frac{1}{2}r_B$ (given) $\therefore \frac{R_A}{R_B} = 16$ or $R_B = \frac{1}{16}R_A = \frac{1}{16}\times24\text{ ohm} = 1.5\text{ ohm}$

ILLUSTRATION : 3.10

Calculate the resistance of 1 km long copper wire of radius 1 mm. (Resistivity of copper is 1.72 × 10^{-8} Ωm)

SOLUTION :

Given: $\ell = 1\text{ km} = 1000\text{m}$, $r = 1\text{ mm} = 10^{-3}\text{ m}$, $A = \pi r^2 = 3.14 \times (10^{-3})^2 = 3.14 \times 10^{-6}\text{ m}^2$

Resistivity $\rho = 1.72 \times 10^{-8}\,\Omega\text{m}$

Resistance, $$R = \rho\frac{l}{A} = \frac{1.72 \times 10^{-8} \times 1000}{3.14 \times 10^{-6}} = 5.5\,\Omega.$$

OHM'S LAW

According to Ohm's law *"The current passing through a conductor is directly proportional to the potential difference between its ends, provided the physical conditions such as temperature of conductor remain unchanged."*

i.e., $V \propto I$ or $V = RI$

where R is a constant which is called resistance of the material.

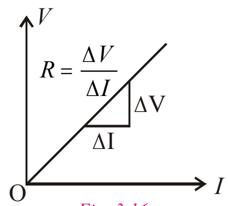


Fig. 3.16

Unit of resistance

$$R = \frac{V}{I} = \frac{\text{volt}}{\text{ampere}} = \text{ohm }(\Omega)$$

The **SI unit** of resistance is ohm (Ω).

If $I = 1$ ampere, $V = 1$ volt then $R = 1\Omega$.

The resistance of a conductor is 1 ohm if a potential difference of 1 volt is produced across its ends when 1 ampere of the current flows through it.

The conductors, which obey the Ohm's law are called the ohmic conductors or linear resistances. All metallic conductors (such as silver, aluminium, copper, iron, etc.) are the **ohmic conductors or linear resistances**.

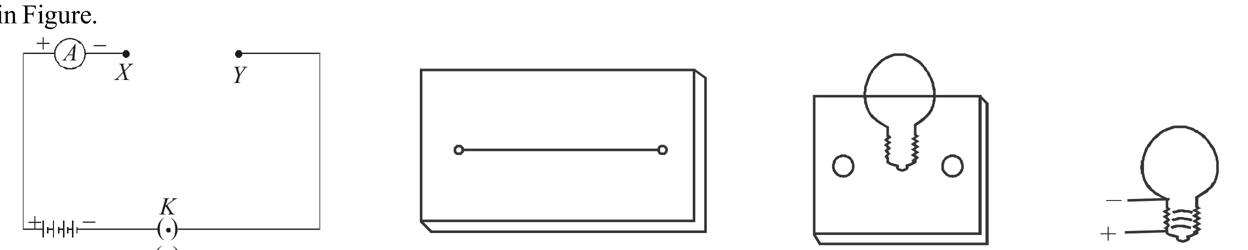
The conductors, which do not obey the Ohm's law are called the **non-ohmic conductors** or **non-linear resistances**. Examples are, diode valve, triode valve, transistors, electrolyte, etc.

Knowledge ENHANCER

It is sometime contended that R = ΔV/i (or ΔV = iR) is a statement of Ohm's law. That is not true! This equation is the defining equation for resistance, and it applies to all conducting devices, whether they obey Ohm's law or not. If we measure the potential difference ΔV across and the current i through the device, even a bulb or other non-ohmic device, we can find its resistance at that value of ΔV as R = ΔV/i. The essence of Ohm's law, however, is a plot of i versus ΔV that it is straight line, so that the value of R is independent of the value of ΔV.

ACTIVITY :

- Take a nichrome wire, a torch bulb, a 10 W bulb and an ammeter (0 – 5 A range), a plug key and some connecting wires.
- Set up the circuit by connecting four dry cells of 1.5 V each in series with the ammeter leaving a gap *XY* in the circuit, as shown in Figure.



(a) (b) Nichrome wire (c) 10W bulb (d) torch bulb

Fig. 3.17

- Complete the circuit by connecting the nichrome wire in the gap XY. Plug the key. Note down the ammeter reading. Take out the key from the plug. Always take out the key from the plug after measuring the current through the circuit.
- Replace the nichrome wire with the torch bulb in the circuit and find the current through it by measuring the reading of the ammeter.

- Now repeat the above step with the 10 W bulb in the gap *XY*.
- Are the ammeter readings differ for different components connected in the gap *XY*? What do the above observations indicate?
- You may repeat this activity by keeping any material component in the gap. Observe the ammeter readings in each case. Analyse the observations.

VERIFICATION OF OHM'S LAW

Set up a circuit as shown in figure with a battery, switch (*S*), a rheostat (*Rh*), ammeter (*a*), a resistor (*R*) and a voltmeter (*V*). Close the circuit and adjust the rheostat such that the ammeter and the voltmeter show a measurable reading *I* and *V* respectively. Repeat the experiment for different values of *I* and *V* by adjusting the rheostat.

Tabulate your results as shown below :

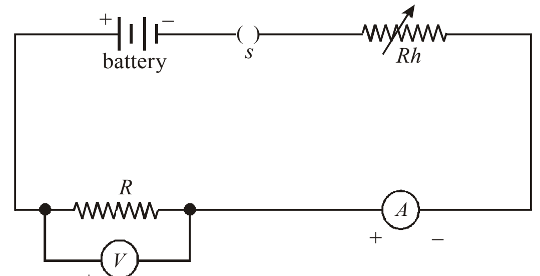


Fig. 3.18

Trial No.	Potential difference V (in volt)	Current I (in ampere)	$\frac{V}{I} = R$ (in ohm)
1.			
2.			
3.			

Plot a graph of *V* against *I*. If it is a straight line passing through the origin Fig. 3.19 we can conclude that P.D. '*V*' is directly proportional to the current '*I*' and Ohm's law is verified.

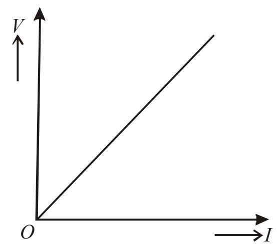


Fig. 4.19

Limitation of Ohm's Law

1. Ohm's law does not apply to conductors such as diode, radio valves, metal rectifiers, electricity through gases.
2. Ohm's law is applicable only when the physical conditions remain constant, for example the resistance of some conductors will vary if the wires are heated or placed under tension.
3. Ohm's law is applicable only when the temperature of the conductor is constant. Generally the resistance of pure metals increases with temperature but the resistance of certain other conducting materials like carbon decreases with temperature. There are certain metal alloys of magnesium and copper whose resistance changes with temperature.

Knowledge ENHANCER

The substances which obey Ohm's law are called Ohmic or linear conductors. The resistance of such conductors is independent of magnitude and polarity of applied potential difference. Here the graph between *I* and *V* is a straight line passing through the origin. The reciprocal of slope of straight line gives resistance

$$R = \frac{\Delta V}{\Delta I} = \frac{1}{\tan\theta} = \text{constant.}$$

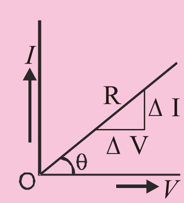


Fig. 3.20 (a)

Examples silver, copper, mercury, carbon, mica etc.

The substances which do not obey Ohm's law are called non-ohmic or non linear conductors. The I–V curve is not a straight line.

Examples *p-n* junction diode, transistors, thermionic valves, rectifiers etc.

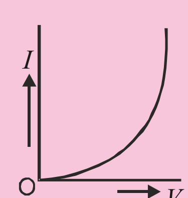


Fig. 3.20 (b)

CHECK Point

Is Ohm's law universally applicable for all conducting elements? If not, give examples of elements which do not obey Ohm's law.

SOLUTION

Ohm's law is not a fundamental law in nature. It is not universally followed semiconductor diodes, transistor, thermistors, vacuum tubes do not follow ohm's law.

ILLUSTRATION : 3.11

Calculate the potential difference required across a conductor of resistance 5Ω to flow a current of 1.5 A through it.

SOLUTION :

Given: $R = 5\Omega$, $I = 1.5\ A$, $V = ?$

From Ohm's, law, $V = IR = 1.5 \times 5 = 7.5\ V$

ILLUSTRATION : 3.12

How much electric current is produced on applying potential difference of 30 volts on a wire of resistance 20 ohm ?

SOLUTION :

Given: Resistance R = 20Ω; potential difference, V = 30V, electric current, I = ?

According to ohm's law,

$$I = \frac{V}{R} = \frac{30}{20} = 1.5 \text{ ampere}$$

ILLUSTRATION : 3.13

If 5 ampere current flowing through a wire, develops a potential difference of 50 volts across its ends, find the resistance of the wire.

SOLUTION :

Here, current I = 5A; potential difference, V = 50V, resistance R = ?

Using ohm's law,

$$R = \frac{V}{I} = \frac{50}{5} = 10 \text{ ohm}$$

ILLUSTRATION : 3.14

The potential difference between the terminals of an electric heater is 60 V when it draws a current of 4A from the source. What current will the heater draw if the potential difference is increased to 120 V?

SOLUTION :

We are given, potential difference $V = 60\ V$, current $I = 4A$.

According to Ohm's law, $R = \frac{V}{I} = \frac{60V}{4A} = 15\ \Omega$

When the potential difference is increased to 120V the current is given by

$$\text{I} = \frac{\text{V}}{\text{R}} = \frac{120\text{V}}{15\Omega} = 8\text{A}$$

The current through the heater becomes 8A.

ILLUSTRATION : 3.15

A relay with a resistance of 12 ohms is in an electric circuit with one side at a potential of 85 volts and the other at 71 volts. How much current is in the relay ?

SOLUTION :

The potential difference across the relay is $(85V - 71V) = 14V$.

Current in the relay, $I = \frac{\Delta V}{R} = \frac{14V}{12\Omega} \simeq 1.2\ A$

COMBINATION OF RESISTORS

In many practical applications to have desired value of resistance two or more resistances are required to be combined. This can be done in two ways : (i) **In series** and (ii) **In parallel**. Sometimes resistances are to be combined in such a way that some resistances be in series and some in parallel. Such a combination is called **mixed grouping**.

If, in an electrical circuit, two or more resistances connected between two points are replaced by a single resistance such that there is no change in the current of the circuit and in the potential difference between those two points, then the single resistance is called the 'equivalent resistance'.

When the resistance of a circuit is to be increased, they are combined in series and when heavy current is to be passed, they are combined in parallel so as to decrease the total resistance.

Series Combination of Resistors

In this combination, the resistances are joined end to end. Thus the second end of each resistance is joined to the first end of the next resistance, and so on. The first end of the first resistance and the second end of the last resistance are connected to the cell.

In this combination, the same current flows in all the resistances but the potential differences between their ends are different according to their resistances.

In figure, three resistances AB, BC and CD are connected in series. Suppose their resistances are R_1, R_2 and R_3 respectively. Let the 'equivalent resistance' of these resistances be R.

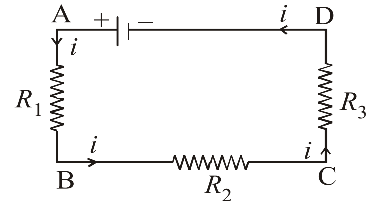


Fig. 3.21

Suppose a current is flowing in all the three resistances. Suppose the potential differences between the ends of the resistances R_1, R_2 and R_3 are V_1, V_2 and V_3 respectively. Then, according to Ohm's law we have

$$V_1 = iR_1, \quad V_2 = iR_2 \quad \text{and} \quad V_3 = iR_3.$$

If the potential difference between points A and D be V, then

$$V = V_1 + V_2 + V_3 = iR_1 + iR_2 + iR_3 = i\,(R_1 + R_2 + R_3) \qquad ....(1)$$

The equivalent resistance between points A and D is R. Therefore

$$V = iR \qquad ....(2)$$

Comparing eq. (1) and (2), we get $\quad iR = i\,(R_1 + R_2 + R_3)$

Therefore, $\quad R = R_1 + R_2 + R_3$

That is, *the equivalent resistance of the resistances connected in series is equal to the sum of those resistances and is thus greater than any individual resistance. Equivalent resistance, $R = R_1 + R_2 + R_3 + ... + R_n$.*

ACTIVITY :

- Join three resistors of different values in series. Connect them with a battery, an ammeter and a plug key, as shown in Fig. You may use the resistors of values like 1Ω, 2Ω, 3Ω etc., and a battery of 6V for performing this activity.
- Plug the key. Note the ammeter reading.
- Change the position of ammeter to anywhere in between the resistors. Note the ammeter reading each time.
- Do you find any change in the value of current through the ammeter ?

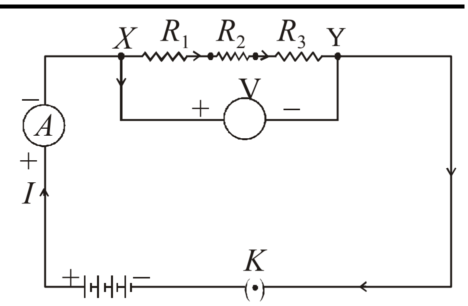


Fig. 3.22

Again,

- In previous activity, insert a voltmeter across the ends X and Y of the series combination of three resistors, as shown in figure.
- Plug the key in the circuit and note the voltmeter reading. It gives the potential difference across the series combination of resistors. Let it be V. Now, measure the potential difference across the two terminals of the battery. Compare the two values.
- Take out the plug key and disconnect the voltmeter. Now, insert the voltmeter across the ends X and P of the first resistor, as shown in Figure.
- Plug the key and measure the potential difference across the first resistor. Let it be V_1.

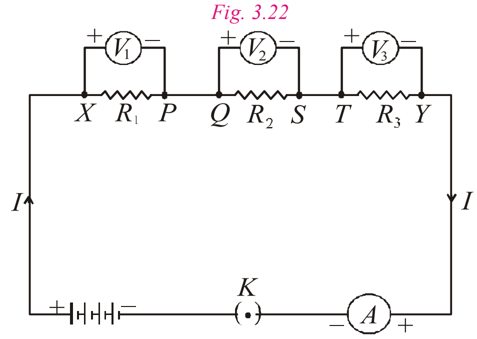


Fig. 3.23

- Similarly, measure the potential difference across the other two resistors, separately. Let these values be V_2 and V_3, respectively.
- Deduce a relationship between V, V_1, V_2 and V_3.

Parallel Combination of Resistors

When two or more resistances are combined in such a way that their first ends are connected to one point and the second ends to another point then this combination is in parallel. *In this combination, the potential difference between the ends of all the resistances is same but the current in different resistances are different.*

In Fig. 3.24, three resistances R_1, R_2 and R_3 are joined in parallel between the points A and B. Suppose the current flowing from the cell is i. At the point A, this current is divided into three parts. Suppose i_1, i_2 and i_3 are the currents in R_1, R_2 and R_3 respectively. At the point B, these three currents meet and form the main current i. Thus, we have

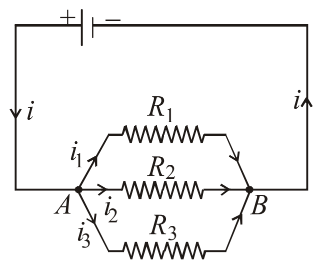


Fig. 3.24

$$i = i_1 + i_2 + i_3 \qquad \text{............. (1)}$$

Let the potential difference between the points A and B be V. Since each resistance is connected between A and B, the potential difference between the ends of each will be V. Therefore,

$$i_1 = \frac{V}{R_1}, \quad i_2 = \frac{V}{R_2} \text{ and } i_3 = \frac{V}{R_3}$$

Substituting these values in eq. (1) we get,

$$i = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \qquad \text{............. (2)}$$

If the equivalent resistance between the points A and B be R, then

$$i = V/R \qquad \text{............. (3)}$$

Comparing eq. (2) and (3), we get

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \quad \text{or} \quad \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

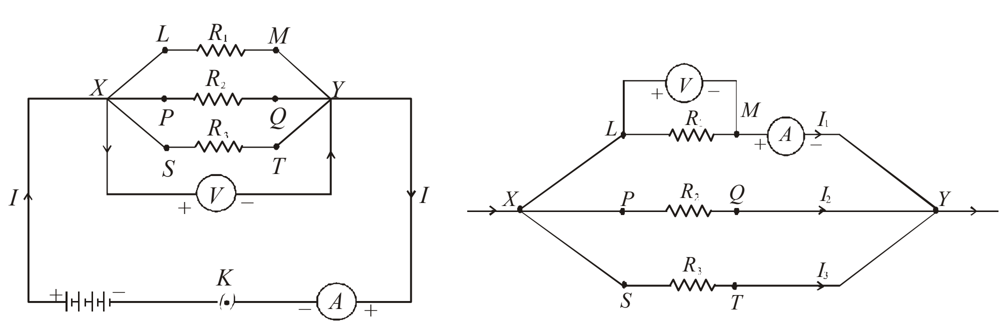
That is, *the reciprocal of the equivalent resistance of the resistances connected in parallel is equal to the sum of the reciprocals of those resistances. Equivalent resistance,* $\frac{1}{R}, = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \dots \frac{1}{R_n}$

In parallel combination, the equivalent resistance R is less than even the smallest resistance connected.

ACTIVITY :

Make a parallel combination, of three resistors having resistances R_1, R_2, and R_3, respectively. Connect it with a battery, a plug key and an ammeter, as shown in Fig 3.25 (a). Also connect a voltmeter in parallel with the combination of resistors.

Plug the key and note the ammeter reading. Let the current be I. Also take the voltmeter reading. It gives the potential difference V, across the combination. The potential difference across each resistor is also V. This can be checked by connecting the voltmeter across each individual resistor [Fig. 3.25(b)].



(a) **(b)**

Fig. 3.25

Take out the plug from the key. Remove the ammeter and voltmeter from the circuit. Insert the ammeter in series with the resist or R_1, as shown in Fig. 3.25 (b). Note the ammeter reading, I_1.

Similarly, measure the currents through R_2 and R_3. Let these be I_2 and I_3, respectively. What is the relationship between I, I_1, I_2 and I_3 ?

CHECK Point

Given n resistors each of resistance R, how will you combine them to get the (i) maximum (ii) minimum effective resistance? What is the ratio of the maximum to minimum resistance?

SOLUTION

(i) For maximum effective resistance, all the resistors should be joined in series.

$R_{max} = R + R + R + ...n$ or $R_{max} = nR$

(ii) For minimum effective resistance all the resistors should be joined in parallel

$$\frac{1}{R_{min}} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} + ...n \quad \text{or} \quad \frac{1}{R_{min}} = \frac{n}{R}$$

So, $R_{min} = \dfrac{R}{n}$

Now, $\dfrac{R_{max}}{R_{min}} = n^2$

ILLUSTRATION : 3.16

Three resistances of 2, 3 and 5 ohms are connected in series. If the combination is connected to a battery of 4 volt then what will be (i) current in each resistance (ii) potential difference across each resistance ?

SOLUTION :

Total resistance in series

$$R = R_1 + R_2 + R_3 = 2 + 3 + 5 = 10\ \Omega.$$

(i) Current flowing through each resistance will be same and is

$$I = \frac{V}{R} = \frac{4}{10} = 0.4 \text{ ampere}$$

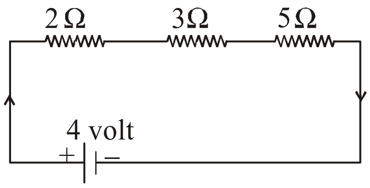


Fig. 3.26

(ii) Potential difference across each resistance will be determined by formula $V = IR$.

Potential difference across 2Ω resistance $V_1 = IR_1 = 0.4 \times 2 = 0.8$ volt
Potential difference across 3Ω resistance $V_2 = IR_2 = 0.4 \times 3 = 1.2$ volt
Potential difference across 5Ω resistance $V_3 = IR_3 = 0.4 \times 5 = 2.0$ volt

ILLUSTRATION : 3.17

Three resistors of 2Ω, 3Ω and 4Ω are connected in (i) series, (ii) parallel. Find the equivalent resistance in each case.

SOLUTION :

Given: $R_1 = 2\Omega$, $R_2 = 3\Omega$ and $R_3 = 4\Omega$

(i) In series, the equivalent resistance

$$R = R_1 + R_2 + R_3 = 2 + 3 + 4 = 9\Omega.$$

(ii) In parallel, the equivalent resistance is R, then

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad \text{or} \quad \frac{1}{R} = \frac{1}{2} + \frac{1}{3} + \frac{1}{4} = \frac{13}{12} \quad \text{or} \quad R = \frac{12}{13}$$

ILLUSTRATION : 3.18

Two resistors of 4Ω and 6Ω are connected in parallel. The combination is connected across a 6V battery of negligible resistance. Calculate the current (i) through the battery (ii) through each resistor. Draw the circuit diagram.

SOLUTION :

The circuit diagram is shown in figure.

(i) If resistance of the combination is R, then

$$\frac{1}{R} = \frac{1}{4} + \frac{1}{6} = \frac{3+2}{12} = \frac{5}{12}$$

or $$R = \frac{12}{5}\Omega = 2.4\ \Omega$$

Let current through the battery be I.

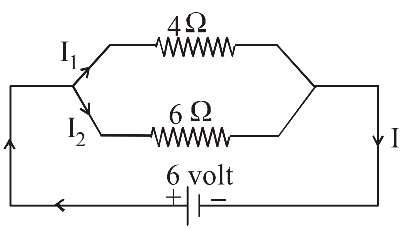


Fig. 3.27

$$I = \frac{V}{R} = \frac{6}{2.4} = 2.5\ A$$

(ii) The potential difference across each resistor is $V = 6$ volt (same as of battery) since they are in parallel.

Current through 4Ω resistor, $I_1 = \frac{V}{R_1} = \frac{6}{4} = 1.5\ A$

Current through 6Ω resistor, $I_2 = \frac{V}{R_2} = \frac{6}{6} = 1\ A$

ILLUSTRATION : 3.19

6Ω and 3Ω resistors are connected in parallel and an 8Ω resistor is connected in series with them. A current of 2A passes through the 8Ω resistor. Find

(a) the combined resistance

(b) the potential difference across the combined resistor

(c) the current through the 3Ω resistor

SOLUTION :

The combined resistance R of the resistors in parallel.

Given: $R_1 = 6\Omega,\ R_2 = 3\Omega,$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{6} + \frac{1}{3} = \frac{3}{6} = \frac{1}{2}$$

or, $R = 2\Omega$

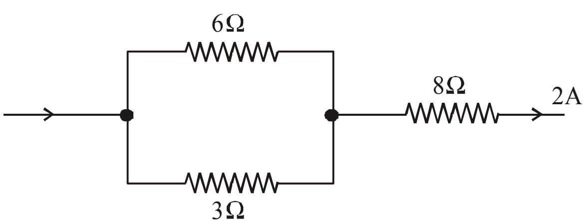


Fig. 3.28 (a)

The equivalent circuit is shown in Fig. 3.28 (b).

Fig. 3.28 (b)

(a) Let the combined resistance of all three resistors be R

$R_1 = 8\Omega,\ R_2 = 2\Omega$

Equivalent resistance, $R = R_1 + R_2 = 8\Omega + 2\Omega = 10\Omega$

(b) Let the potential difference across the combined resistors be V.

$V = ?\ ,\ I = 2A,\ R = 10\Omega$

$V = I \times R = 2A \times 10\Omega = 20V$

(c) The combined resistance of the parallel network is 2Ω. Hence potential difference V across the parallel resistor is

$V = I \times R = 2A \times 2\Omega = 4V$

For the 3Ω resistor $V = 4V,\ I = ?,\ R = 3\Omega$

$$I = \frac{V}{R} = \frac{4V}{3\Omega} = 1\frac{1}{3}\ A$$

ILLUSTRATION : 3.20

Three resistors are connected in series to 24 volt battery, and an ammeter in the circuit reads 0.50 amperes. The first resistor is rated at 22 ohms, and the second at 8 ohms. Find (a) the total resistance (b) the resistance of the third resistor, and

(c) the potential difference across the third resistor.

SOLUTION :

Given: Current in the circuit, I = 0.5A; V = 24V

(a) The total resistance of the circuit

$$R = \frac{\Delta V}{I} = \frac{24V}{0.50\ A} = 48\ \Omega$$

(b) In a series circuit, resistance add, so $22\ \Omega + 8\Omega + R_3 = 48\Omega \Rightarrow R_3 = 18\Omega$.

(c) For any circuit element, $\Delta V = IR$ so $V_3 = (0.50\,A)\,(18\,\Omega) = 9V$

ILLUSTRATION : 3.21

In the circuit shown, find :

(a) the equivalent resistance between points A and B.

(b) the current through the battery

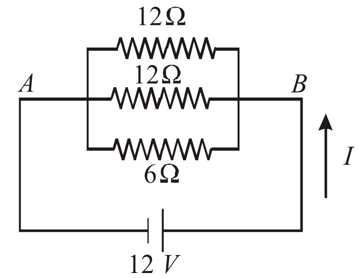


Fig. 3.29

SOLUTION :

Given : $R_1 = 12\Omega,\ R_2 = 12\Omega,\ R_3 = 6.0\,\Omega,\ V = 12V$

(a) The three resistors are in a parallel combination.

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{12\Omega} + \frac{1}{12\Omega} + \frac{1}{6.0\Omega} = \frac{1}{12\Omega} + \frac{1}{12\Omega} + \frac{2}{12\Omega} = \frac{4}{12\Omega} = \frac{1}{3.0\Omega}$$

(b) From Ohm's law, $I = \dfrac{V}{R} = \dfrac{V}{R_p} = \dfrac{12V}{3.0\Omega} = 4.0\,A$

Knowledge ENHANCER

Conversion of galvanometer into ammeter and voltmeter

Galvanometer: A galvanometer is an instrument which is used to measure current or voltage, as per requirement.

Ammeter: It is a low resistance galvanometer used to measure strength of current in an electrical circuit.

An ammeter is always connected in series in a circuit because when an ammeter is connected in series it does not appreciably change the resistance of circuit and hence the main current flowing through the circuit. An ideal ammeter has zero resistance.

The reading of an ammeter is always less than actual current in the circuit because all practical ammeters have low finite resistance.

Smaller is the resistance of an ammeter more accurate will be the reading.

A galvanometer can be converted to an ammeter by connecting a low resistance shunt in parallel to coil of galvanometer.

Here, $I_g\,G = (I - I_g)\,S$ or $S = \dfrac{I_g}{I - I_g}G$

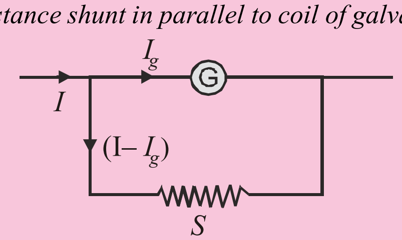


Fig. 3.30

Here G is resistance of galvanometer and I_g is current required to produce full scale deflection of current.

Shunt (S) is a low resistance connected in parallel to coil of galvanometer to convert it to ammeter. It protects a galvanometer from strong currents. It is also used to alter range of an ammeter.

The resistance of converted ammeter is $R_A = \dfrac{G.S}{G+S}$

The range of an ammeter is increased by reducing shunt resistance *S*.

If $I = N\,I_g$ then $S = \dfrac{I_g}{NI_g - I_g}G = \dfrac{G}{N-1}$

The range of an ammeter can be increased N times by reducing shunt to $S = G/N\text{-}1$.

It is possible to increase the range of an ammeter because it lowers the resistance of ammeter further.

The length of the shunt required $\ell = \pi r^2 S/\rho$ where r is radius of shunt wire and ρ is specific resistance of material of shunt wire.

Reducing the shunt resistance may increase range but it reduces the sensitivity.

Voltmeter : It is a high resistance galvanometer used to measure potential difference.

A voltmeter is connected in parallel to a circuit element because when connected in parallel it draws least current from the main current. So it measures nearly accurate potential difference.

An ideal voltmeter has infinite resistance.

The reading of a voltmeter is always less than actual value because all practical voltmeter may have large but finite resistance. Greater is the resistance of voltmeter more accurate is its reading.

A galvanometer can be converted to a voltmeter by connecting a high resistance in series with coil of galvanometer.

$$V = I_g (R + G) \qquad \text{or} \qquad R = \frac{V}{I_g} - G$$

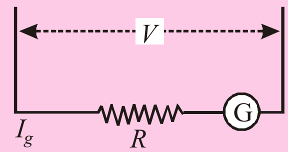


Fig. 3.31

The resistance of converted voltmeter is $R_v = R + G$

The range of a voltmeter is increased by increasing the series resistance.

$$\text{If} \qquad V = NV_g = NI_g G \text{ then } R = \frac{NI_g G - G}{I_g} = (N-1)G$$

The value of resistance required to increase range N times is $R = (N-1)G$

CONNECTING TOPIC

KIRCHHOFF'S LAW

This law is used to solve a problem regarding electrical circuit.

(i) Kirchhoff's first law or current law or junction rule

In any electrical network, the algebraic sum of currents meeting at a junction is always zero i.e. $\Sigma I = 0$

$$I_1 - I_2 + I_3 + I_4 - I_5 = 0 \qquad \text{or} \qquad I_1 + I_3 + I_4 = I_2 + I_5$$

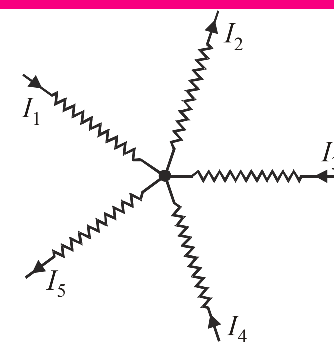


Fig. 3.32

The sum of currents flowing towards a junction is equal to sum of currents leaving the junction.

By convention the current directed towards the junction is positive while those directed away from the junction is taken as negative.

The first law is in accordance with conservation of charge.

The charges do not accumulate at a junction. The total charge entering a junction is equal to total charge leaving the junction.

(ii) Kirchhoff's second law or voltage law or loop rule

The algebraic sum of all the potential drops and emf's along any closed path in a network is zero. i.e. $\Sigma V = 0$

The second law is in accordance with conservation of energy.

According to second law, the electric energy given to the charge by a source of emf is lost in passing through resistance.

The change in potential in covering a resistance in the direction of current is negative ($-IR$) while in opposite direction it is positive.

$$V_A - IR = V_B \qquad\qquad V_B + IR = V_A$$
$$V_B - V_A = IR \qquad\qquad V_A - V_B = IR$$

(a) **(b)**

Fig. 3.33

The potential falls along the direction of current. The potential fall is taken as negative while potential rise is taken as positive. The emf of source is taken as positive when it is traversed from negative to positive terminal while it is taken as negative when it is traversed from positive to negative irrespective of the direction of current.

$$V_A - E = V_B \qquad\qquad V_B + E = V_A$$
$$V_B - V_A = -E \qquad\qquad V_A - V_B = E$$

(a) **(b)**

Fig. 3.34

If there are n loops their will be $(n-1)$ equations according to loop rule.

The algebraic sum of products of currents and resistances in a closed loop is equal to sum of emf's applied in the circuit i.e., $\Sigma E = \Sigma IR$.

WHEATSTONE BRIDGE

It is an arrangement of four resistances devised by Charles Wheatstone which is used to measure an unknown resistance.
The Wheatstone bridge principle states that if four resistances P, Q, R and S are arranged to form a bridge with a cell and key between A and C, and a galvanometer between B and D then bridge is said to be balanced when galvanometer shows a zero deflection.

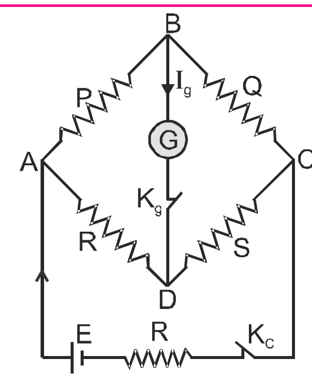


Fig. 3.35

In This is called **condition of balanced wheatstone bridge**.

The condition of balanced wheatstone bridge depends on resistance P, Q, R and S. This is independent of emf of battery.
In state of balance the cell and galvanometer can be interchanged.
While performing an experiment at start press the cell key K_c first and then the galvanometer key K_g and at end remove K_g first and then K_c to avoid induced effects.
P and Q are called ratio arms, R is known as resistance arm and S is the unknown arm. BD and AC are called conjugate arms.

The resistance of balanced Wheatstone bridge between A and C is $\dfrac{(P+Q)(R+S)}{P+Q+R+S}$.

The sensitivity of bridge depends upon value of resistances. The sensitivity is maximum when P, Q, R and S are of same order.
Unbalanced Wheatstone bridge

In unbalanced bridge $I_g \neq 0,\ V_B \neq V_D$ so $\dfrac{P}{Q} \neq \dfrac{R}{S}$.

If $\dfrac{P}{Q} < \dfrac{R}{S}$ then $V_B > V_D$ so current flows from B to D.

If $\dfrac{P}{Q} > \dfrac{R}{S}$ then $V_B < V_D$ so current flows from D to B.

METRE BRIDGE

The metre bridge, shown, is a practical arrangement of the Wheatstone's bridge. It consists of a 1m-long resistance wire AC of the uniform cross-sectional area and uniform material, i.e., magnanin, or constantan, having the high electrical resistivity of low temperature coefficient.

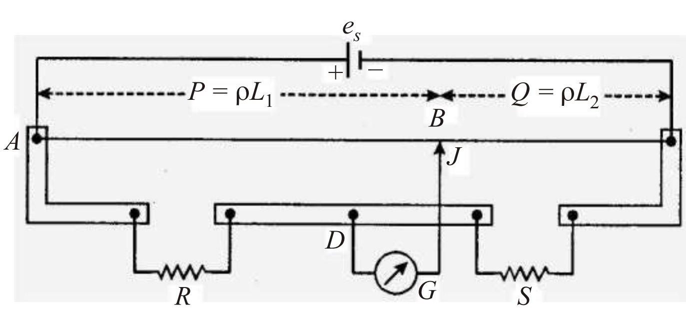


Fig. 3.36 : Metre Bridge

A null situation is obtained by moving the jockey J on the bridge wire AC till no deflection is observed in the galvanometer. Now, the balance condition gives

$$\frac{R}{S} = \frac{P}{Q} \quad \Rightarrow \quad \frac{R}{S} = \frac{\rho L_1}{\rho L_2} = \frac{L_1}{L_2}$$

$$\Rightarrow \quad \frac{R}{S} \quad \text{or,} \quad \frac{R}{S} = \frac{L_1}{(1 - L_1)}$$

where ρ is the resistance per unit length of the bridge wire.

HEATING EFFECT OF ELECTRIC CURRENT

When the electric current is passed through a conductor then conductor gets heated, this effect is known as the heating effect of current.

As current flows through a conductor, the free electrons lose energy which is converted into heat.

Heat produced in a conductor by electric current

Consider a conductor XY of resistance R ohm. Let the potential difference (in volts) be applied across the ends of XY. Let the steady current (in ampere) that passes from end X to end Y be I. If this current flows for t seconds, then the amount of electric charge transferred from point X to Y is

$$Q = I \times t \qquad ...(1)$$

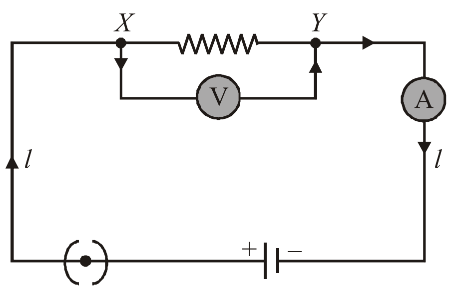


Fig. 3.37 A steady current in a purely resistive electric circuit

When an electric charge Q moves against a potential difference V, the amount of work done (W) is given by

$$W = Q \times V \qquad ...(2)$$

According to Ohm's law, $R = \dfrac{V}{I}$

or potential difference, $V = I \times R$ ...(3)

Now, substituting the values of Q from equation (1) and V from equation (3) in equation (2), we get

$W = I \times t \times I \times R$

$H = I^2 \times R \times t$

This work done is called electrical work done. The electric circuit is purely resistive, i.e., the conductor XY has resistance only, connected to the battery so all the electrical energy consumed is converted into heat energy. Then amount of heat produced

$W = H = I^2 \times R \times t$

or $H = I^2 \times R \times t$ ...(4)

Equation (4), i.e., $H = I^2 \times R \times t$ is known as **Joule's law of heating.**

Joule's Law of Heating Effect: It states that the amount of heat produced in a conductor is

(i) directly proportional to the square of current passing through it,

$H \;\alpha\; I^2$ .... (i)

(ii) directly propotional to the resistance of conductor,

$H \;\alpha\; R$ .... (ii)

(iii) directly proportional to the time for which current passed ,

$H \;\alpha\; t$ .... (iii)

Combining eqs. (i), (ii) and (iii).

$H \;\alpha\; I^2 Rt.$

Here, constant of proportionality is 1.

Therefore, heat produced in a conductor, $H = I^2 Rt$ *joule*

PRACTICAL APPLICATION OF HEATING EFFECT

The heat generated when current passes through a resistive material is used in many common devices. The material through which the current passes is surrounded by an insulating substance in order to prevent the current from flowing through the cook to the earth when he or she touches the pan.

Hair dryer, in which a fan blows air past heating coils. In this case the warm air can be used to dry hair, but on a broader scale this same principle is used to dry clothes and to heat buildings.

Other practical application includes heater, toaster, electric kettle etc.

DOMESTIC ELECTRIC CIRCUITS

Electricity from power stations is transmitted to homes through high voltage power lines. Electric potentials as high as 220 000 *V* AC are used. The electrical potential is decreased to 220 *V AC* with the help of step-down transformer before it enters the home. A cable containing three colour-coded wires enters the home. One wire is red, one is black, and one is green. The red wires are called live wires (or positive). Another wire with the black insulation is called neutral wires (or negative). There is an electrical potential difference of 220 V AC between a red and a black wire. The earth wire, which has insulation of green colour, is usually connected to a metal plate deep in the earth near the house. This is used as a safety measure, especially for those appliances that have a metallic body, for example, electric press, toaster, table fan, refrigerator, etc. The metallic body is connected to the earth wire, which provides a low-resistance conducting path for the current. Thus, it ensures that any leakage of current to the metallic body of the appliance keeps its potential to that of the earth, and the user may not get a severe electric shock.

Fuses and Circuit Breakers

A fuse is a safety device that acts as a switch. Fuses are connected into the circuit close to the source. As a result all the current flowing in the circuit passes through the fuse. When too much current flows, the fuse heats up sufficiently to bum out. This creates an air gap and no more current flows. The construction of a plug fuse is shown in Figure. Other kinds of fuses are cartridge fuses and knife blade fuses. The essential part is the fuse wire or a blade with a low melting point.

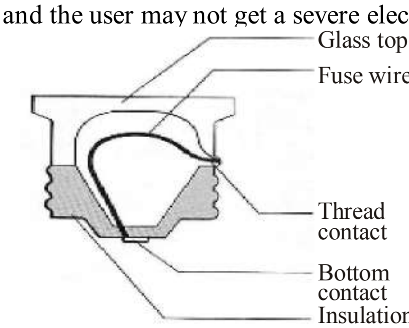


Fig. 3.38 A plug fuse

Most homes built in recent years use circuit breakers instead of fuses in their electrical panels. A circuit breaker is connected in the same place as a fuse would be, and it performs the same function. When too much current flows, the circuit breaker simply opens like a switch. Then, when the problem that caused the excess current has been corrected, you can close the breaker again.

Circuit Breaker Panel

At the home, the electricity first passes through an electric meter. The electric meter records the amount of electric energy used in the home. Then the electricity enters a circuit breaker panel. (In some older homes it may enter a fuse panel.) In this panel there is a master circuit breaker. The master circuit breaker can be operated manually to cut off the electricity to the entire home. It opens automatically if the current exceeds the -rated value. In homes that have a 100 A service, the master circuit breaker will allow up to 100 A to pass before it pops open.

There are three strips of conducting metal called bus bars in the breaker panel. The red wire is connected to one, the black wire to another, and the white wire to the third. As a result, two of the bus bars are live and one is neutral.

Electric Circuits in the Home

All the electric circuits within the home originate from the bus bars. Figure shows a 220 V AC cable going to a stove. Notice that the cable is connected to all three bus bars. This cable has two circuit breakers, one for the black wire and one for the red wire. Each major appliance has its own 220 V AC circuit.

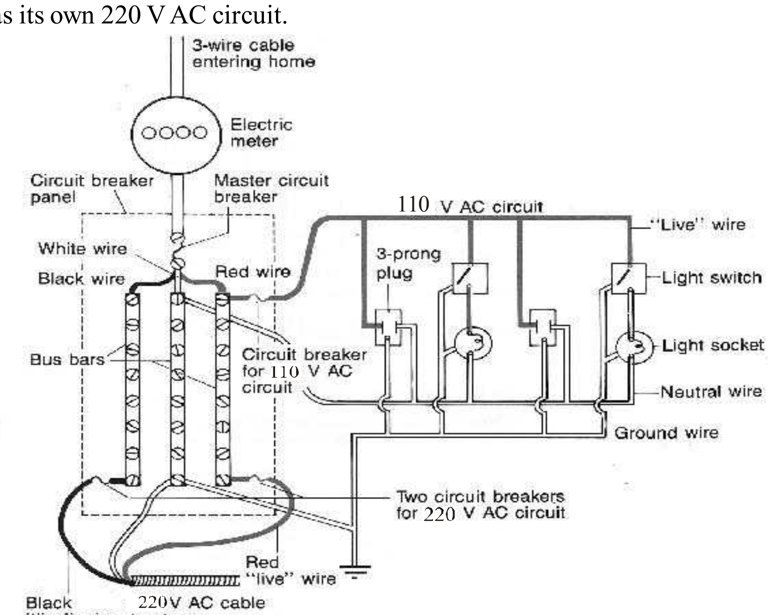


Fig. 3.39

A 110 V AC circuit is also shown. Notice that only two of the bus bars are used, the neutral bus bar and either of the live bus bars. This circuit also has its own circuit breaker. The 110 V AC circuit consists of the circuit breaker, two three-prong plugs, and two light fixtures and two switches. A ground wire connects all switch and outlet boxes to ground and to the neutral bus bar. This prevents injury if the boxes become live.

Loads in the same circuit, such as wall outlets and lights, are always connected in parallel. If one load bums out the others still operate. Also, as more and more loads are turned on, the electrical potential remains the same. However, the electric current increases. But one load does not affect another unless the circuit becomes overloaded.

Causes of Overloaded Circuits

There are two main causes of overloaded circuits. First, an appliance or a conducting wire can develop a short circuit. Now the current is no longer limited by the load. In this case, current passes from the live wire to the neutral wire or from the live wire to the ground wire without passing through the load. The current becomes very large very fast. This heats up the circuit.

Second, too many appliances can be plugged into the same circuit. Each appliance draws a certain current. The combination can draw too much current and the circuit again heats up.

A circuit breaker is designed to prevent overloading. It trips and opens the circuit as soon as the circuit becomes too hot.

CHECK Point

Why are devices in household circuits almost never connected in series?

SOLUTION

The devices in household circuits are never connected in series because if they are connected so they cannot be turned on or off separately as required. If one of the device will be turned off then all of them will also be turned off. Moreover, if the devices are lighting one, their brightness will decrease if more devices will be added.

ELECTRIC POWER

If a battery is used to establish an electric current in a conductor, there is a continuous transformation of chemical energy stored in the battery to kinetic energy of the charge carriers. This kinetic energy is quickly lost as a result of collisions between the charge carriers and the lattice ions, resulting in an increase in the temperature of the conductor. Therefore, we see that the chemical energy stored in the battery is continuously transformed into heat energy.

Consider a simple circuit consisting of a battery whose terminals are connected to a resistor R, as shown in figure 3.40.

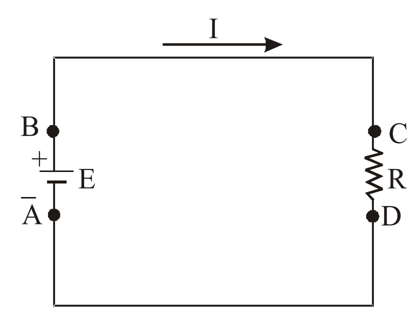


Fig.3.40

The positive terminal of the battery (the longer plate) is at the higher potential, while the negative terminal (the shorter plate) is at the lower potential. Now imagine a positive quantity of charge ΔQ moving around the circuit from point A through the battery and resistor and back to A. Point A is a reference point that is grounded, and its potential is taken to be zero. As the charge moves from A to B through the battery, its electrical potential energy increases by an amount $V\Delta Q$ (where V is the potential at B) while the chemical potential energy in the battery decreases by the same amount. However, as the charge moves from C to D through the resistor, it loses this electrical potential energy as it undergoes collisions with atoms in the resistor, thereby producing thermal energy. Note that if we neglect the resistance of the interconnecting wires there is no loss in energy for paths BC and DA. When the charge returns to point A, it must have the same potential energy (zero) as it has at the start.

The rate at which the charge ΔQ loses potential energy in going through the resistor is given by

$$\frac{\Delta U}{\Delta t} = \frac{\Delta Q}{\Delta t}V = IV$$

where I is the current in the circuit. Of course, the charge regains this energy when it passes through the battery. Since the rate at which the charge loses energy equals the power P lost in the resistor, we have

$$P = IV \qquad \text{............ (1)}$$

In this case, the power is supplied to a resistor by a battery. However, eq. (1) can be used to determine the power transferred to any device carrying a current I and having a potential difference V between its terminals.

Using eq. (1) and the fact that $V = IR$ for a resistor, we can express the power dissipated in the alternative forms

$$P = I^2 R = \frac{V^2}{R}$$

When I is in amperes, V in volts, and R in ohms, the SI unit of power is the watt (W). The power lost as heat in a conductor of resistance R is called joule heating.

Watt is a small unit of power, its other bigger units are Kilowatt (KW), Megawatt (MW) and Horsepower (HP).

1 kW = 1000 W = 10^3 W
1 MW = 1000000 W = 10^6 W
1 hp = 746 W

If 100W – 220V is written on the bulb then it means that the bulb will consume 100 joule in one second if used at the potential difference of 220 volts.

The value of electricity consumed in houses is decided on the basis of the total electric energy used.

Electric power tells us about the electric energy used per second not the total electric energy.

The total energy used in a circuit = power of the electric circuit × time

If the power is in watt and time is in second, then the electric energy will be in joule or watt × second.

As the watt × sec is a small unit of energy, electric energy is measured in Kilowatt Hour (kWh) **Board of trade unit (B.O.T.U).**

1 Kilowatt hour (kWh) = 1000 watt hour
= 1000 × 60 × 60 watt sec = 36000000 joule = 3.6 × 10^6 joule

1 kWh is called the 1 unit.

The electricity department uses this unit in the electric bills. If the 100 watt bulb or any other electric appliance is used for an hour then the total electric energy consumed is 1 kWh or 1 unit.

CHECK Point

The wattage marked on a light bulb is not an inherent property of the bulb rather, it depends on the voltage to which it is connected, usually 110 or 120V. How many amperes current flow through a 60-W bulb connected in a 120-V circuit?

SOLUTION

Using the formula, Watt = volt × ampere

$$60 = 120 \times \text{ampere} \Rightarrow \text{ampere} = \frac{60}{120} = 0.5A$$

Thus, a 0.5 A current flows through a 60-W bulb connected in a 120-V circuit

ILLUSTRATION : 3.22

An electric refrigerator rated 400W operates 8 hours/day. What is the cost of the energy to operate it for 30 days at ₹ 3.00 per unit ?

SOLUTION :

The total energy consumed by the refrigerator in 30 days would be
400W × 8.0 hours/day × 30 days = 96999 Wh = 96 k Wh or 96 unit
Thus the cost of energy to operate the refrigerator for 30 days
96 kWh × ₹ 3.00 = ₹ 288.00

ILLUSTRATION : 3.23

What is the operating resistance of a 100-watt household light bulb ? The operating line voltage of household electricity is 120V.

SOLUTION :

Given : P = 100 W, V = 120 V, R. = ?

From $P = \frac{V^2}{R}$, we have $R = \frac{V^2}{P} = \frac{(120V)^2}{100W} = 144\ \Omega$

ILLUSTRATION : 3.24

On a 220V power line the powers of two electric bulbs are 60W and 30W separately. Find the powers of their parallel and series combinations when connected on the same line.

SOLUTION :

The resistance of the 220V-60W rated bulb $R_1 = \frac{V^2}{P_1} = \frac{(220)^2}{60}\ \Omega$

The resistance of the 220V-30W rated bulb $R_2 = \frac{V^2}{P_2} = \frac{(220)^2}{30}\ \Omega$

When the bulbs are connected in parallel, their equivalent resistance $R = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{\frac{(220)^2}{60} \times \frac{(220)^2}{30}}{\frac{(220)^2}{60} + \frac{(220)^2}{30}} = \frac{(220)^2}{90}\ \Omega$

The power of the parallel combination $P = \frac{V^2}{R} = \frac{(220V)^2}{\{(220)^2/90\}\Omega} = 90W$

When the bulbs are connected in series, their equivalent resistance $R' = R_1 + R_2 = \frac{(220)^2}{60} + \frac{(220)^2}{30} = (220)^2 \times \frac{1}{20}\Omega$

Power $P' = \frac{V^2}{R'} = \frac{(220V)^2}{\{(220)^2 \times 1/20\}\Omega} = 20W$

ILLUSTRATION : 3.25

An electric kettle has coils A and B. When coil A is switched on, the water boils in 10 minutes, and when coil B is switched on, the water boils in 20 minutes. Calculate the time taken by the water to boil if the coils connected in (a) series and in (b) parallel are switched on.

SOLUTION :

Let R_1 and R_2 be the resistances of the coils A and B respectively, and t_1 and t_2 the time-intervals taken by the water to boil when A and B are switched on turn by turn. If W be the heat energy required to boil the water, then

$$W = \frac{V^2 t_1}{R_1} = \frac{V^2 t_2}{R_2} \quad \text{where } V \text{ is supply voltage.}$$

This gives $\frac{R_2}{R_1} = \frac{t_2}{t_1}$ ..... (1)

Here $t_1 = 10$ min and $t_2 = 20$ min. $\therefore \frac{R_2}{R_1} = \frac{20}{10} = 2$ or $R_2 = 2R_1$

(a) When the coils are connected in series, the equivalent resistance is

$$R = R_1 + R_2 = R_1 + 2R_1 = 3R_1.$$

If t be the time taken by the water to boil, then from eq. (1), we have

$$\frac{R}{R_1} = \frac{t}{t_1} \ ;\ t = 3t_1 = 30 \text{ min.} \qquad [\because R/R_1 = 3]$$

(b) When the coils are connected in parallel, the equivalent resistance is $R' = \frac{R_1 R_2}{R_1 + R_2} = \frac{R_1(2R_1)}{R_1 + 2R_1} = \frac{2}{3}R_1$

If t' be the time taken by the water to boil, then from eq. (1) , we have

$$\frac{R'}{R_1} = \frac{t'}{t_1} \quad \text{or} \quad t' = \frac{2}{3}t_1 = \frac{20}{3}\text{min} \qquad [\because R'/R_1 = 2/3 \text{ and } t_1 = 10 \text{ min}]$$

ILLUSTRATION : 3.265.14

Two bulbs A and B are rated 100W, 120V and 10W, 120V respectively. They are connected across a 120V source in series. Calculate the current through each bulb. Which bulb will consume more energy ?

SOLUTION :

Resistance of bulb A (rating 100W, 120V) is $R_1 = \frac{V^2}{P_1} = \frac{(120)^2}{100} = 144\ \Omega$

Resistance of bulb B (rating 10W, 120V) is $R_2 = \frac{V^2}{P_2} = \frac{(120)^2}{10} = 1440\ \Omega$

When they are connected in series,
Total resistance, $R = R_1 + R_2 = 144 + 1440 = 1584\Omega$

Current in the circuit $I = \frac{V}{R} = \frac{120}{1584} = 0.076A$

Same current passes through each bulb.
Power consumed in the bulb A is $P_1 = I^2R_1$.
Power consumed in the bulb B is $P_2 = I^2R_2$.
Since, $R_1 < R_2$ $\therefore$ $P_1 < P_2$.
Hence, the bulb B (rated 10W, 120V) consumes more energy than the bulb A (rated 100W, 120V) when they are connected in series.

ILLUSTRATION : 3.27

There are 5 rooms in a house. Each room has a 100W bulb and a 40W tube light. If every day the bulb is used for 1 hour and tube light is used for 5 hours in each room then what will be the cost of total electric energy consumed in 30 days when 1 unit of electric energy costs ₹ 2.5.

SOLUTION :

Energy used every day in 5 bulbs = 5 × 100 × 1 Wh = 500 Wh
Energy used everyday in 5 tube lights = 5 × 40 × 5 Wh = 1000 Wh
Total energy used everyday by bulb and tube light = (500 + 1000) Wh = 1500 Wh

Total energy used in 30 day = 1500 × 30 Wh = 45000 Wh = $\frac{45000}{1000}$ KWh = 45 KWh (unit)

Cost of the total energy used = 45 × 2.50 = ₹ 112.50

ILLUSTRATION : 3.28

Compute the heat generated while transferring 96000 coulomb of charge in one hour through a potential difference of 50 V.

SOLUTION :

Here, $Q = 96{,}000\ C$, $t = 1$ hour = 60 × 60s, V = 50 V

Current, $I = \frac{Q}{t} = \frac{96000}{60 \times 60} = \frac{80}{3} A$

Resistance, $R = \frac{V}{I} = \frac{50 \times 3}{80} = \frac{15}{8}\Omega$

Heat produced, $H = I^2Rt = \frac{80}{3} \times \frac{80}{3} \times \frac{15}{8} \times 60 \times 60 = 4800000$ J = 4800 kJ

CONNECTING TOPIC

CHEMICAL EFFECT OF ELECTRIC CURRENT

Electric current can produce chemical change. This ability of current is called chemical effect. This effect is shown by D.C. only. A.C. current cannot produce chemical effect.

FARADAY'S LAWS OF ELECTROLYSIS

(i) **1st law :** The mass of the substance liberated or deposited at an electrode during electrolysis is directly proportional to the quantity of charge passed through the electrolyte
i.e., $m \propto q$ or $m = Zq = Z$ It, where Z = electrochemical equivalent (E.C.E.) of substance.

(ii) **2nd law :** When the same amount of charge is passed through different electrolytes, the masses of the substance liberated or deposited at the various electrodes are proportional to their chemical equivalents

i.e. $\frac{m_1}{m_2} = \frac{E_1}{E_2}$ where m_1 & m_2 are the masses of the substances liberated or deposited on electrodes during electrolysis and E_1 & E_2 are their chemical equivalents.

Faraday Constant: Faraday constant is equal to the amount of charge required to liberate the mass of a substance at an electrode during electrolysis, equal to its chemical equivalent in gram (i.e. one gram equivalent)
One faraday $1F$ = 96500 C/gram equivalent.

ELECTROCHEMICAL CELL-PRIMARY AND SECONDARY CELLS

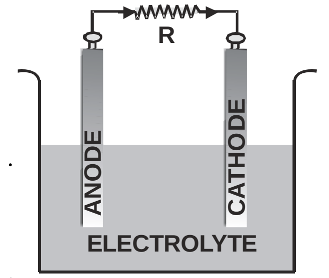


Fig. 3.41

An electrochemical cell is a device which by converting chemical energy into electrical energy maintains the flow of charge in a circuit. It usually consists of two electrodes of different materials and an electrolyte. The electrode at higher potential is called anode and the one at lower potential is cathode

Primary Cells: The cells which cannot be recharged electrically are called primary cells. Here the original state of cell cannot be brought back by passing electrical energy through cell from external source after cell is discharged.

e.g. Voltaic cell, Daniel cell, Leclanche cell, manganese-alkaline cell, mercury button cell etc.

Secondary Cells: The cells in which chemical process is reversible are called secondary cells. Here original chemical state of cell can be brought back by passing electrical energy through cell from external source.

e.g. Lead acid accumulator, alkali cells etc.

ELECTROMOTIVE FORCE (EMF)

The emf of a cell is defined as the work done by cell in moving a unit positive charge in the whole circuit including the cell.

Emf $E = W/q$; Its **SI unit** is joule/coulomb or volt.

Emf is the maximum potential difference between the two electrodes of the cell when no current is drawn from the cell. It is the characteristic property of cell and depends on the nature of electrodes and electrolyte used in cell, and is independent of quantity of electrolyte, size of electrodes and distance between the electrodes.

Internal Resistance of Cell: *The opposition offered by the electrolyte of the cell to the flow of electric current through it is called the internal resistance of the cell.* The internal resistance of cell depends on

- Distance between electrodes ($r \propto d$), larger is the separation between electrodes more is the length of electrolyte through which ions have to move so more is internal resistance.
- Conductivity or nature of electrolyte ($r \propto 1/\sigma$)
- Concentration of electrolyte ($r \propto c$),
- Temperature of electrolyte ($r \propto 1/T$)
- Nature and area of electrodes dipped in electrolyte ($r \propto 1/A$)

TERMINAL POTENTIAL DIFFERENCE

The potential difference between the two electrodes of a cell in a closed circuit i.e., when current is being drawn from the cell is called terminal potential difference.

(a) When cell is discharging

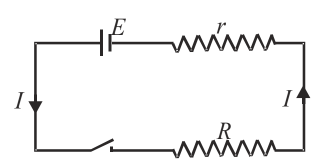


Fig.3.42

When cell is discharging current inside the cell is from anode to cathode .

Current $I = \dfrac{E}{r+R}$ or $E = IR + Ir = V + Ir$ or $V = E - Ir$

When current is drawn from the cell, potential difference is less than emf of cell. Greater is the current drawn from the cell smaller is the terminal voltage. When a large current is drawn from a cell, its terminal voltage is reduced.

(b) When cell is charging

When cell is charging current inside the cell is from cathode to anode.

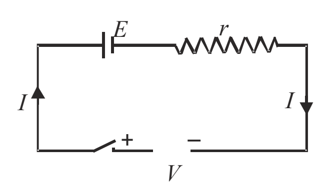


Fig. 3.43

Current $I = \dfrac{V-E}{r}$ or $V = E + Ir$

During charging terminal potential difference is greater than emf of cell.

(c) When cell is in open circuit

In open circuit, $R = \infty$ $\therefore$ $I = \dfrac{E}{R+r} = 0$ so $V = E$

In open circuit terminal potential difference is equal to emf and is the maximum potential difference which a cell can provide.

(d) When cell is short circuited

In short circuit, $R = 0$ so $I = \dfrac{E}{R+r} = \dfrac{E}{r}$ and $V = IR = 0$

In short circuit current from cell is maximum and terminal potential difference is zero.

(e) Power transferred to load by cell

$$P = I^2 R = \frac{E^2 R}{(r+R)^2}$$

$$P = P_{max} \text{ if } r = R$$

Power transferred by cell to load is maximum when $r = R$ and $P_{max} = \frac{E^2}{4r} = \frac{E^2}{4R}$

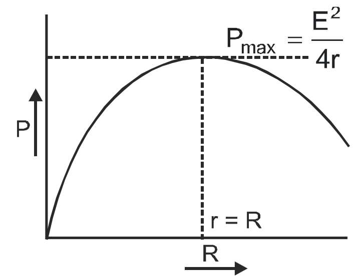


Fig. 3.44

Difference Between emf and Potential Difference

Emf of a cell	Potential difference
1. The emf of a cell is the maximum potential difference between the two electrodes of a cell when the cell is in the open circuit.	**1.** The potential difference between the two points is the difference of potential between these two points in a closed circuit.
2. Emf is independent of resistance of circuit and depends upon the nature of electrodes and electrolyte.	**2.** This depends upon the resistance between two points of the circuit and current flowing through the circuit.
3. The term emf is used for source of current.	**3.** Potential difference can be measured between any two points of circuit.
4. This is a cause.	**4.** It is an effect.

GROUPING OF CELLS

(i) **Series Combination of Cells**

The cells are said to be connected in series if negative terminal of first is connected to positive of second whose negative terminal is connected to positive of third cell. The external resistance is connected between free terminals of first and last cells.

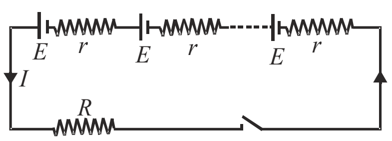


Fig.3.45 (a)

Let n identical cells each of emf E and internal resistance r be connected in series. The combination can be replaced by a single cell of emf nE and internal resistance nr. The current flowing through load $I = \frac{nE}{R + nr}$

If $nr << R$ then $I = \frac{nE}{R}$. If equivalent internal resistance nr is less than external resistance R then current in circuit is equal to n times circuit current due to single cell.

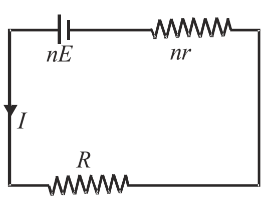


Fig.3.45 (b)

If $nr >> R$ then $I = E/r$. If equivalent internal resistance nr is greater than external resistance R then current in circuit is equal to short circuited current obtained from one cell.

Maximum current can be drawn from series combination of cells if external resistance is very large as compared to equivalent internal resistance.

If in series combination of n cells, p cells are reversed then equivalent emf

$$E_{eq} = (n-p)\,E - pE = (n-2p)E \qquad \text{and} \qquad r_{eq} = nr \quad \text{So current } I = \frac{(n-2p)E}{nr + R}$$

If unidentical cells are connected in series then

$$E_{eq} = E_1 + E_2 + ... = \Sigma E_i \text{ and } \qquad r_{eq} = r_1 + r_2 + ... = \Sigma r_i.$$

$$\therefore \quad \text{Current, } I = \frac{\Sigma E_i}{R + \Sigma r_i}.$$

(ii) Parallel Combination of Cells

The cells are said to be connected in parallel if positive terminals of all the cells are connected together at one point and their negative terminals at another point. The external resistance or is connected between these two points.

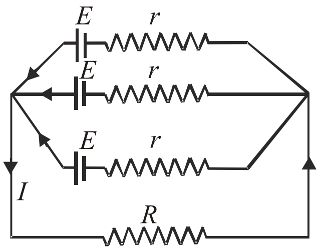


Fig.3.46 (a)

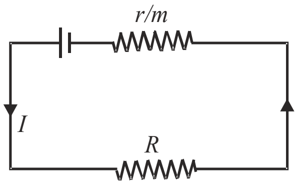


Fig.3.46 (b)

Let m identical cells each of emf E and internal resistance r be connected in parallel. The combination can be replaced by a single cell of emf E and internal resistance r/m. The current $I = \dfrac{E}{R + r/m}$.

If $r/m << R$ then $I = \dfrac{E}{R}$. If equivalent internal resistance r/m is less than external resistance R then current in circuit is equal to current produced by a single cell.

If $r/m >> R$ then $I = \dfrac{mE}{r}$. If equivalent internal resistance $\dfrac{r}{m}$ is greater than external resistance then current in circuit is equal to m times the current produced by a short circuited cell.

Thus maximum current can be drawn from parallel combination of cells if external resistance is small as compared to net internal resistance of cells.

(iii) Mixed Combination of Cells

If the mn number of identical sources are combined, as shown, where we have the m number of rows of sources in parallel and the n number of sources in series in each row, the total emf of combination becomes ne_s and the total internal resistance of combination becomes nr/m. Then, the electric current through the load is

$$I = \frac{ne_s}{\left(\dfrac{nr}{m} + R\right)} = \frac{e_s}{\left(\dfrac{r}{m} + \dfrac{R}{n}\right)}$$

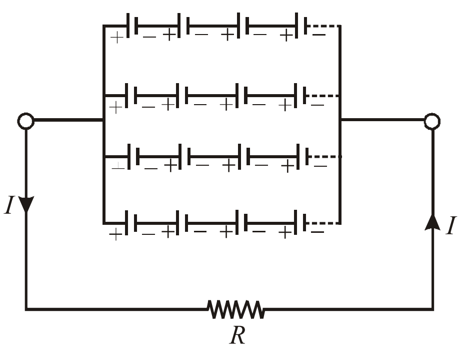


Fig.3.47

And the electrical power delivered to the load is

$$P_{load} = RI^2 = R\frac{n^2 e_s^2}{\left(\dfrac{nr}{m} + R\right)^2} = R\frac{e_s^2}{\left(\dfrac{r}{m} + \dfrac{R}{n}\right)^2}$$

Which is maximum under the condition of total internal and external resistances being equal, *i.e.,* $R = \dfrac{nr}{m}$

MISCELLANEOUS SOLVED EXAMPLES

1. **If 3.0×10^{15} electrons flow through a section of a wire of diameter 2.0 mm in 4.0 s, what is the electric current in the wire?**

Sol. Given: $n = 3.0 \times 10^{15}$ electrons, $t = 4.0\ s$, $d = 2.0$ mm.
The charge in 3.0×10^{15} electrons $q = ne = (3.0 \times 10^{15}$ electrons$) \times (1.60 \times 10^{-19}$ C/electrons$) = 4.8 \times 10^{-4} C$

So, current, $I = \dfrac{q}{t} = \dfrac{4.8\times10^{4} C}{4.0\ s} = 1.2\times10^{4}\ A = 0.12$ mA

2. **Two copper wires A and B of length 30 m and 10 m have radius 2 mm and 1 mm respectively. Compare the resistance of the two wires. Which will have less resistance ?**

Sol. From the relation Resistance, $R = \rho\dfrac{\ell}{A}$

Resistance of wire A is $R_A = \rho\dfrac{30}{\pi\,(2\times10^{-3})^2}$

Resistance of wire B is $R_B = \rho\dfrac{10}{\pi\,(1\times10^{-3})^2}$

On dividing $\dfrac{R_A}{R_B} = \dfrac{30}{10}\left(\dfrac{1\times10^{-3}}{2\times10^{-3}}\right)^2 = \dfrac{3}{4}$

Thus the wire A has less resistance.

3. **Resistance of a metal wire of length 1 m is 26 Ω at 20°C. If the diameter of the wire is 0.3 mm, what will be the resistivity of the metal at that temperature?**

Sol. We are given the resistance R of the wire = 26 Ω, the diameter $d = 0.3$ mm $= 3 \times 10^{-4}$ m, and the length l of the wire = 1 m.
Therefore, from the resistivity of the given metallic wire $\rho = (RA/l) = (R\pi d^2/4l)$
Substitution of values in this gives $\rho = 1.84 \times 10^{-8}$ Ω m
The resistivity of the metal at 20°C is 1.84×10^{-8} Ω m.

4. **A nichrome wire has a resistance of 10Ω. Find the resistance of another nichrome wire, whose length is three times and area of cross-section four times the first wire.**

Sol. **Case 1 :** $R = 10$ Ω. Let ℓ be length and 'a' the area of cross-section.

$\therefore \quad R = \rho\dfrac{\ell}{a} \quad$ or $\quad 10 = \rho\dfrac{\ell}{a}$ .... (1)

Case 2 : $R_1 = ?$, length $= 3\ell$, area $= 4a$

$\therefore \quad R_1 = \rho\dfrac{3\ell}{4a}$ .... (2)

Dividing eq. (2) by (1)

$\dfrac{R_1}{10} = \dfrac{\rho.3\ell}{4a}\times\dfrac{a}{\rho.\ell} \quad \therefore \quad R_1 = 10\times\dfrac{3}{4} = 7.5\ \Omega$

5. **(a) How much current will an electric bulb draw from a 220 V source, if the resistance of the bulb filament is 1200 Ω ?**
(b) How much current will an electric heater coil draw from a 220 V source, if the resistance of the heater coil is 100 Ω?

Sol. (a) We are given $V = 220\ V$; $R = 1200$ Ω.
From eq. $R = V/I$, we have the current $I = 220\ V/1200\ \Omega = 0.18\ A$.
(b) We are given, $V = 220\ V$, $R = 100$ Ω.
From eq. $R = V/I$, we have the current $I = 220\ V/100\ \Omega = 2.2\ A$.

6. **An electric lamp of resistance 100 Ω, a toaster of resistance 50 Ω, and a water filter of resistance 500 Ω are connected in parallel to a 220V source. What is the resistance of an electric iron connected to the same source that takes as much current as all three appliances, and what is the current through it?**

Sol. Here, $R_l = 100\ \Omega$, $R_t = 50\ \Omega$, $R_f = 500\Omega$, $V = 220$ volt,

Current I drawn by, lamp $= I_\ell = \frac{V}{R_\ell} = \frac{220}{100} = 2.2A$

By toaster $I_t = \frac{220}{50} = 4.4A$, and by water filter $I_f = \frac{220}{500} = 0.44A$

Total current drawn $= I_l + I_t + I_f = 7.04$ A

Current to be drawn by iron = 7.04 A

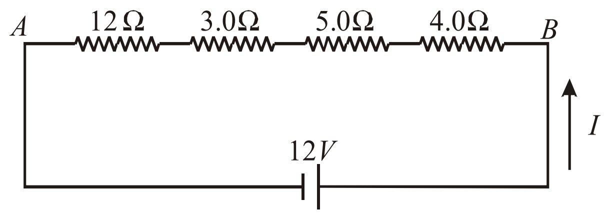
Resistance of electric iron $R_1 = \frac{V}{I} = \frac{220}{7.04} = 31.25\Omega$

7. How much energy is given to each coulomb of charge passing through a 6 V battery ?

Sol. Energy = charge × potential difference

$= 1 \times 6 = 6$ joule

8. In the circuit shown, find : (a) the equivalent resistance between points A and B, (b) the current through each resistor.



Sol. Given : $R_1 = 12\ \Omega$, $R_2 = 3.0\ \Omega$, $R_3 = 5.0\ \Omega$, $R_4 = 4.0\ \Omega$, $V = 12V$.

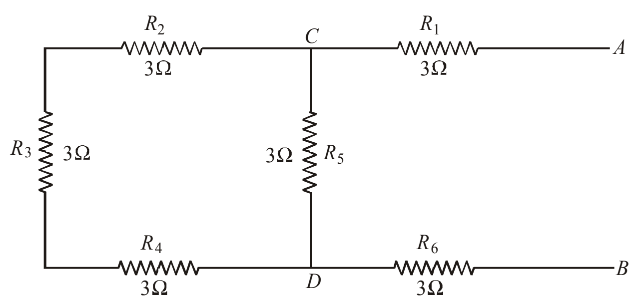
(a) All four resistors are in series combination, so

$$R_s = R_1 + R_2 + R_3 + R_4 = 12\Omega + 3.0\Omega + 5.0\Omega + 4.0\Omega = 24\Omega$$

(b) The current through all resistors in series is the same

$$I = \frac{V}{R} = \frac{V}{R_s} = \frac{12V}{24\Omega} = 0.50\ A$$

9. For the combination of resistors shown in figure, find the equivalent resistance between (i) C and D (ii) A and B.



Sol. **(i)** The resistors R_2, R_3, R_4 are in series. They can be replaced by an equivalent resistance R', where

$R' = R_2 + R_3 + R_4 = 3 + 3 + 3 = 9\Omega$.

The resistance R_5 (= 3Ω) and R'(= 9Ω) are in parallel, between the points C and D. The equivalent resistance between C and D is R'', $\frac{1}{R''} = \frac{1}{3} + \frac{1}{9}$ or $\frac{1}{R''} = \frac{3+1}{9} = \frac{4}{9}$ or $R'' = \frac{9}{4} = 2.25\ \Omega$

Thus the equivalent resistance between C and D is 2.25 Ω

(ii) Now the resistor R_1 = (3Ω), R'' (= 2.25Ω) and R_6 (= 3Ω) are in series between the points A and B.

The equivalent resistance between A and B is : $R = R_1 + R'' + R_6 = 3 + 2.25 + 3 = 8.25\Omega$

10. What is (a) the highest, (b) the lowest total resistance that can be secured by combinations of four coils of resistance 4 Ω, 8 Ω, 12 Ω and 24 Ω ?

Sol. (a) Highest – By connecting the resistors in series. So, $R = 4 + 8 + 12 + 24 = 48\ \Omega$

(b) Lowest – By connecting the resistors in parallel.

So, $\frac{1}{R} = \frac{1}{4} + \frac{1}{8} + \frac{1}{12} + \frac{1}{24}$ $\therefore$ $R = \frac{24}{6+3+2+1} = \frac{24}{12} = 2\Omega$

11. How many 176Ω resistors (in parallel) are required to carry a current of 5 A on a 220 *V* line?

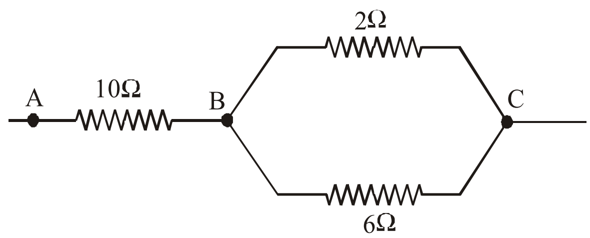
Sol. When N resistors each $R\ \Omega$ are in parallel

$$R_p = \frac{R}{N}$$

Current drawn from cell = I = $\frac{V}{R_{eq}} = \frac{VN}{R}$

$$\therefore \quad N = \frac{IR}{V} = \frac{5 \times 176}{220} = 4$$

12. Calculate the equivalent resistance between points *A* and *C*, as shown in figure.



Sol. Resistances 2Ω and 6Ω are connected in parallel between points B and C. Let R_p be their equivalent resistance.

$$\frac{1}{R_p} = \frac{1}{2} + \frac{1}{6} = \frac{4}{6} = \frac{2}{3} \qquad \text{or} \qquad R_p = \frac{3}{2} = 1.5\ \Omega$$

Now, equivalent resistance R_p is in series with 10Ω resistance.

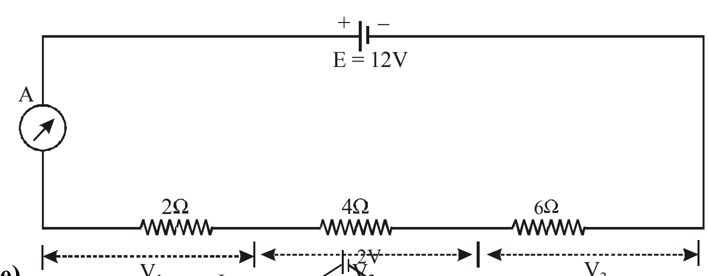
Therefore, equivalent resistance of circuit $\quad R_s = 10 + 1.5 = 11.5\Omega$.

13. Three resistors of 2Ω, 4Ω and 6Ω are connected in series to a battery of emf 12V and negligible internal resistance. Draw the circuit diagram and calculate (i) current drawn from cell (ii) p.d. at the ends of each resistor.

Sol. The circuit diagram is shown in figure

Resistance of 2Ω, 4Ω and 6Ω in series.

$\therefore\ R = 2 + 4 + 6 = 12\Omega$



(i) $\therefore$ Current drawn from cell (I) = $\frac{V}{R} = \frac{12}{12} = 1A$

(ii) P.D. across 2Ω resistor $V_1 = I.R_1 = 1 \times 2 = 2V$

P.D. across 4Ω resistor $V_2 = I.R_2 = 1 \times 4 = 4V$

P.D. across 6Ω resistor $V_3 = I.R_3 = 1 \times 6 = 6V$

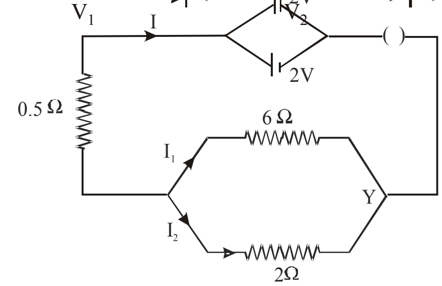
14. Two cells of 2V each are connected in parallel (figure). An external resistance of 0.5Ω is connected in series to the junction of two parallel resistors of 6Ω and 2Ω and then to the common terminal of the battery through each resistor.

Calculate the

(i) total resistance of the circuit.

(ii) current flowing through 0.5Ω resistors

(iii) current flowing through 6Ω resistor.



Sol. EMF of the battery = $2V$

Effective resistance of the parallel resistors is given by R_1

$$\frac{1}{R_1} = \frac{1}{6} + \frac{1}{2} = \frac{1+3}{6} = \frac{4}{6} = \frac{2}{3} \Rightarrow R_1 = \frac{3}{2} = 1.5\ \Omega$$

(i) Total resistance of the circuit, $R = 1.5 + 0.5 = 2\Omega$

(ii) Current flowing through 0.5Ω coil = 1A $\qquad$ [$\because$ Main current $I = \frac{V}{R} = \frac{2}{2} = 1A$]

P.D. across the junctions : $V_1 = IR_1 = 1 \times 1.5 = 1.5\text{V}$

(iii) Hence, current I_1, flowing through 6Ω resistor $I_1 = \frac{V_1}{6} = \frac{1.5}{6} = 0.25\ A$

15. Two coils of resistance 3Ω and 6Ω are connected across a battery of emf 12V. Find the electrical energy consumed in 1 minute in each resistance when they are connected in series. Draw the circuit diagram.

Sol. The circuit diagram is shown in figure.

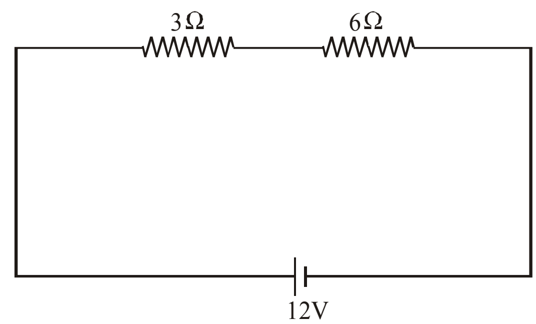
Total resistance of the circuit $R = 3 + 6 = 9\Omega$.

Current in the circuit $I = \frac{V}{R} = \frac{12}{9} = \frac{4}{3} A$

Since the resistance are in series, same current flows in each resistance.

Electrical energy spent in $R_1 = I^2R_1t = \left(\frac{4}{3}\right)^2 \times 3 \times 60 = 320$ J

Electrical energy spent in $R_2 = I^2R_2t = \left(\frac{4}{3}\right)^2 \times 6 \times 60 = 640$ J



16. A bulb has voltage rating of 220 V and power rating of 40 W. How can this bulb be made to glow with normal brightness if a voltage source of e.m.f. 330 V is available?

Sol. Here $V = 220\ V$; P = 40 W

Resistance of the bulb, $R = \frac{V^2}{P} = \frac{(220)^2}{40} = 1210\,\Omega$

Current in the circuit, $I = \frac{E}{R+S} = \frac{330}{1210+S}$

Potential difference across the bulb, $IR = \left(\frac{330}{1210+S}\right)1210$

As per question, $220 = \frac{330 \times 1210}{1210+S}$

On solving, we get $S = 605\ \Omega$

17. If two bulbs of wattage 25 W and 30 W, each rated at 220 volts are connected in series with a 440 volt supply, which bulb will fuse?

Sol. Resistance of 25 W bulb, $R_1 = \frac{(220)^2}{25}\Omega$; Current $I_1 = \frac{25}{220}A$

Resistance of 30 W bulb, $R_2 = \frac{(220)^2}{30}\Omega$, Current $I_2 = \frac{30}{220}A$

When bulbs are connected in series, effective resistance is

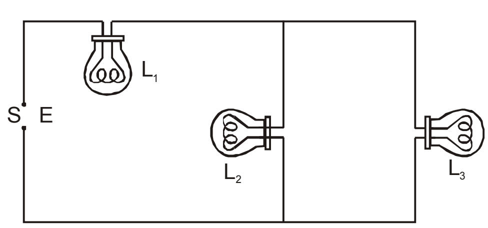
$$R = R_1 + R_2 = (220)^2\left[\frac{1}{25} + \frac{1}{30}\right] = 220 \times 220 \times \frac{11}{150}\Omega$$

When supply voltage is 440 V, then current

$$I' = \frac{440}{R} = \frac{440 \times 150}{220 \times 220 \times 11} = \frac{27.27}{220}A$$

As $I' > I_1$ but less than I_2, hence the bulb of 25 watt will fuse.

18. Fig. shows three similar lamps L_1, L_2 and L_3 connected across a power supply. If the lamp L_3 fuse, how will the light emitted by L_1 and L_2 change?



Sol. Let R be the resistance of each lamp. If E be the applied e.m.f., then the current in the circuit, I_1, is given by

$$I_1 = \frac{E}{R+(R/2)} = \frac{2E}{3R}$$

Current flowing through L_2 or $L_3 = \frac{1}{2}\left[\frac{2E}{3R}\right] = \frac{E}{3R}$

When L_3 is fused, the whole current flows through L_1 and L_2.

Thus, $\quad I_2 = \frac{E}{R+R} = \frac{E}{2R}$

So, current through L_1 decreases and through L_2 increases.

19. 1 kW heater is to be used with 220 V d.c. supply. (i) What is the current in the heater? (ii) What is its resistance?

Sol. Given: power p = 1 kw = 1000W : V = 220 V

(i) Current in the heater, $I = P/V = 1000/220 = 4.5\ A$

(ii) Resistance $R = V^2/P = (220)^2/1000 = 48.4\ \Omega$

20. A fuse wire with a circular cross section and having diameter of 0.4 mm blows with a current of 3 amp. What will be the value of the current for which another fuse wire made of the same material but having circular cross-section with diameter of 0.06 mm will blow?

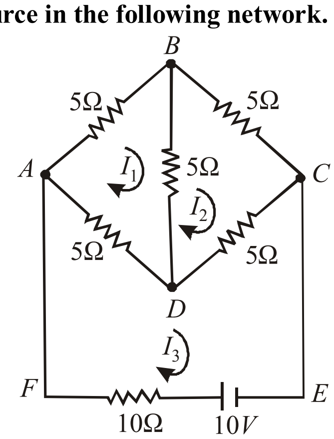
Sol. Here, $I_1 = 3A$; $I_2 = ?$ $r_1 = \frac{0.04}{2} = 0.02$ cm and $r_2 = \frac{0.06}{2} = 0.03$ cm

For a fuse wire $I^2 \propto r^3 \qquad \therefore \frac{I_1^2}{I_2^2} = \frac{r_1^3}{r_2^3}$

$$\therefore \frac{(3)^2}{I_2^2} = \left(\frac{0.02}{0.03}\right)^3 = \left(\frac{2}{3}\right)^3 \quad \text{or} \quad I_2^2 = (3)^2\left(\frac{3}{2}\right)^3 \quad \text{or} \quad I_2 = 3\times\left(\frac{3}{2}\right)^{3/2} = \sqrt{\frac{243}{8}}$$

SOLVED EXAMPLES BASED ON CONNECTING TOPICS

21. Determine the current through the dc source in the following network.



Sol. We assume the loop, or mesh, currents I_1, I_2 and I_3 in the loops, or meshes, *ABDA*, *BCDB* and *ADCEFA,* respectively, and arbitrarily select their directions clockwise, as shown, and traversal direction also clockwise.

Applying the Kirchhoff's voltage law to the three loops, we have respectively,

$$+ I_1 \times 10 + (I_1 - I_3)\,5 + (I_1 - I_3)\,5 = 0 \Rightarrow 4I_1 - I_2 = I_3 \quad \text{....(1)}$$

$$+ I_2 \times 5 + (I_2 - I_3)\,10 + (I_2 - I_1)\,5 = 0 \Rightarrow -I_1 + 4I_2 = 2I_3 \quad \text{....(2)}$$

$$+ (I_3 - I_1)\,5 + (I_3 - I_2)\,10 + I_3 \times 10 = 10 \Rightarrow -I_1 - 2I_2 + 5I_3 = 2 \quad \text{....(3)}$$

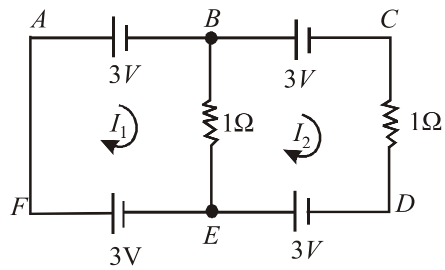
Solving equations (1) and (2), we get

$$I_1 = \frac{2I_3}{5} \text{ and } I_2 = \frac{3I_3}{5}$$

Again, substituting these values of I_1 and I_2 into equation (3), we get the current through the dc source, i.e.,

$$I_3 = \frac{10}{17} A.$$

22. Calculate the current in each resistance in the given circuit.



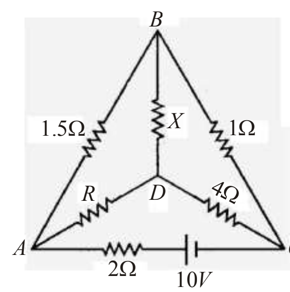
Sol. Let us assume the loop currents I_1 and I_2 in the clockwise direction in the two meshes *ABEFA* and *BCDEB,* respectively. Let us also assume the traversal direction in the clockwise sense. Then, the equations for the two loops are, respectively,

$$(I_1 - I_2) \times 1 = +3 - 3 \Rightarrow I_1 = I_2$$

The current in the resistance of 1Ω between *B* and *E*

$$I_{BE} = I_1 - I_2 = 0$$

23. If the current through the branch *BD* of the circuit, shown, is zero. Find the resistance *R* and current through it.

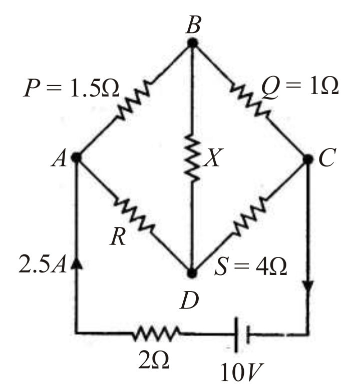


Sol. The given circuit, when rearranged, is found to be a Wheastone's bridge circuit, as shown.

Since, the current through the branch *BD* is zero, the bridge is balanced, i.e.,

$$\frac{P}{Q} = \frac{R}{S} \Rightarrow \frac{1.5}{1} = \frac{R}{4}$$

$$\Rightarrow R = 4 \times 1.5 = 6\Omega$$



The branch *BD* is ineffective as it carries no current and, therefore, we have two parallel paths *ABC* and *ADC* of the resistances 2.5Ω and 10Ω, respectively. The combined resistance between *A* and *C* becomes

$$R_{AC} = \frac{2.5 \times 10}{(2.5 + 10)} = \frac{25}{12.5} = 2\Omega$$

Further, this resistance is connected in series with the resistance of 2Ω so that the total resistance becomes (2 + 2) = 4Ω. The current from the source is

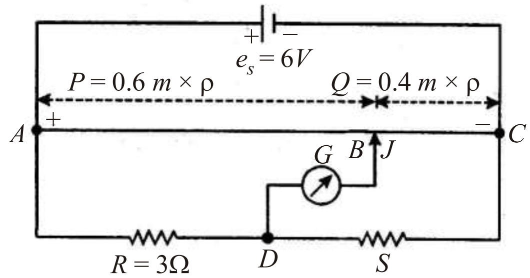
$$I = \frac{10}{4} = 2.5A$$

Then, the current through the resistance *R* is given by

$$I_R \times (R + 4) = I \times (R_{AC})$$

$$I_R \times (6 + 4) = 2.5 \times 2 \qquad I_R = \frac{2.5 \times 2}{10} = 0.5A.$$

24. A metre bridge circuit is shown in the balanced state. The bridge wire *AC* has a resistance per metre ρ = 100Ω/m. Calculate the unknown resistance *S* and the current drawn from the dc source of emf of 6 *V* and negligible internal resistance.



Sol. From the balance condition, we have

$$\frac{P}{Q} = \frac{R}{S} \Rightarrow \frac{0.6 \times 100}{0.4 \times 100} = \frac{3}{S} \Rightarrow S = \frac{4 \times 3}{6} = 2\Omega$$

The equivalent resistance between A and C is given by

$$R_{AC} = \frac{(P+Q)(R+S)}{(P+Q)+(R+S)} = \frac{(1\times100)(3+2)}{(1\times100)+(3+2)} = \frac{100\times5}{100+5} = \frac{500}{105}\Omega$$

Then, the current drawn from the dc source $I = \frac{6}{R_{AC}} = \frac{6\times105}{500} = \frac{630}{500} = 1.26A$

25. A dry cell of e.m.f. 1.5 V and internal resistance 0.10Ω connected across a resistor in series with a very low resistance ammeter. When the circuit is switched on, the ammeter reading settles to a steady value of 2.0 A. What is the steady
(i) rate of chemical energy consumption of the cell?
(ii) rate of energy dissipation inside the cell?
(iii) rate of energy dissipation inside the resistor and
(iv) power output of the source ?

Sol. Let R be the external resistance, then

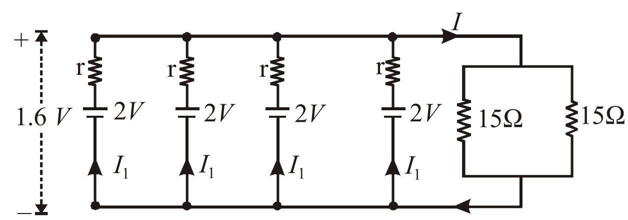
$$(R+r) = \frac{V}{i} = \frac{1.5}{2.0} = 0.75\Omega$$

$\therefore\ R = 0.75 - r = 0.75 - 0.10 = 0.65\ \Omega$

(i) The rate of consumption of chemical energy of the cell = $V\times i = 1.5\times2.0 = 3.0\ W$
(ii) The rate of energy dissipation inside the internal resistor = $i^2r = (2.0)^2\times0.10 = 0.4\ W$
(iii) The rate of energy dissipation inside the external resistor = $i^2R = (2.0)^2\times0.65 = 2.6\ W$
(iv) The power output of the source
= total power – rate of energy dissipation inside the cell
= $3.0 - 0.4 = 2.6\ W$

26. Four identical cells, each of emf e_s = 2V, are joined in parallel, providing a current to the external circuit which consists of two resistances, each of 15Ω, in parallel. The terminal voltage of the cells is 1.6 V. Calculate the internal resistance *r* of each cell.

Sol. The complete circuit diagram, consisting of the 4 identical cells and the two external resistances in parallel, is shown.



The total emf in the circuit is $e_s' = e_s = 2V$, the total internal resistance is $r/4$ and the total external resistance is $15/2 = 7.5\Omega$.

Therefore, the current through the total external resistance is

$$I = \frac{E}{R+r} = \frac{2}{\left(\frac{r}{4}+7.5\right)} = \frac{8}{(r+30)}$$

And the terminal voltage across the cells $V = e_s' - I\left(\frac{r}{4}\right)$

$$\Rightarrow \quad 1.6 = 2 - \frac{8}{(r+30)}\times\frac{r}{4} = \frac{60}{(r+30)} \quad \Rightarrow \quad r = 7.5\Omega.$$

27. If 64 cells of emf e_s = 2V and internal resistance *r* = 2Ω, are connected in *m* rows, each consisting of *n* cells in series, then find out these values of *m* and *n* for getting the maximum current through an external resistance *R* = 8Ω.

Sol. The current through the external resistance R is given by

$$I = \frac{ne_s}{\left(\frac{nr}{m}+R\right)} = \frac{(mn)e_s}{(nr+mR)} = \frac{(64)\times2}{(n\times2+m\times8)}$$

$$= \frac{64}{(n+4m)} = \frac{64}{\left(n+\frac{4\times64}{n}\right)} = \frac{64}{\left(n+\frac{256}{n}\right)}$$

where $mn = 64$ is the total number of cells. The current will be maximum, when the denominator is minimum, *i.e.,* when

$$\frac{d}{dn}\left(n+\frac{256}{n}\right) = 0 \quad \Rightarrow \quad 1 - \frac{256}{n^2} = 0$$

$$\Rightarrow \quad n = 16 \text{ and }, \quad \Rightarrow \quad m = \frac{64}{n} = 4.$$

1 EXERCISE

Fill in the Blanks :

DIRECTIONS : *Complete the following statements with an appropriate word / term to be filled in the blank space(s).*

1. The rate of flow of electric charge is called ....
2. If there is no current, a voltmeter connected across a resistor will register..................... voltage.
3. Combined resistance is the sum of separate resistances provided that the various conductors are connected in ....
4. In a parallel circuit, each circuit element has the same ....
5. Copper is a preferred material for making wire because of its low.......................
6. The S.I. unit of electric current is ....
7. .... is a property that resists the flow of electrons in a conductor.
8. The S.I. unit of resistance is ....
9. The potential difference across the ends of a resistor is .... to the current through it, provided its .... remains the same.
10. The resistance of a conductor depends directly on its ...., inversely on its ...., and also on the .... of the conductor.
11. 1 volt × 1 coulomb ....
12. Potential difference is a .... quantity.
13. The resistance of a semiconductor .... with increase in temp.
14. The S.I. unit of resistivity is ....
15. Physical quantity represented by coulomb per second is ....
16. Two resistances of 2 Ω each are connected in parallel. The equivalent resistance is ....
17. The resistance of a wire is .... proportional to the square of its radius.
18. Kilowatt is the unit of electrical .... but kilowatt-hour is the unit of electrical ....
19. Energy spent in kilowatt-hour

$$= \frac{\text{volt} \times \ldots\ldots\ldots \times \ldots\ldots\ldots\ldots}{1000}$$

20. A fuse is a short piece of wire of high .... and low ....
21. Fuse wire has a .... melting point and is made of an alloy of ....and .... If the current in a circuit rises too high, the fuse wire ....
22. A fuse is connected in .... to the .... wire.
23. Electric energy is produced by the .... of charges.
24. Energy converted per unit charge is measured with an instrument called a (*n*).....................
25. The electrical energy dissipated in a resistor is given by W = ...
26. The unit of power is ....
27. One watt of power is consumed when 1 A of current flows at a potential difference of ....
28. 1 kW h = ...
29. The alloy which is used for making the filament of bulbs is ....
30. Power transmission is carried out at high......................... and low ....
31. Rate at which electric work is done is called ....

True / False :

DIRECTIONS : *Read the following statements and write your answer as true or false.*

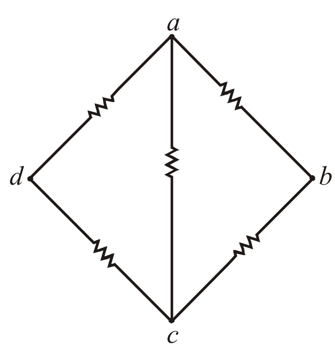
1. A copper wire of length *L* and cross-sectional area *A* carries a current *I*. If the specific resistance of copper is *S*, then electric field in the wire is *IS/A*.
2. The temperature coefficient of resistance of a wire is 0.00125/°C. The resistance of the wire is 1 ohm at 300 K. The resistance will be 2 ohm at 1100 K.
3. The quantity of charge flowing past a point multiplied by time is a current.
4. The resistivity of all pure metals increases with the rise in temperature.
5. Ohm's law is a relation between the power used in a circuit to the current and the potential difference.
6. Direction of current is taken opposite to the direction of flow of electrons.
7. The equivalent resistance of several resistors in series is equal to the sum of their individual resistances.
8. In parallel combination, the reciprocal of equivalent resistance is the sum of the reciprocal of individual resistance.
9. The series arrangement is used for domestic circuits.
10. The reciprocal of resistance is called specific resistance.
11. Resistivity is measured in ohm-metre.
12. The resistance of a wire is directly proportional to length.
13. The resistance of a wire is directly proportional to area.
14. The resistivity of alloys decreases with the rise in temp.
15. Metals have high resistivity.
16. The filament resistance of glowing bulb is greater, to its resistance when it is not glowing ?
17. The commercial unit of electrical energy is kilowatt-hour (kWh).
18. Pure tungsten has high resistivity and a high melting point (nearly 3000°C).
19. When a metallic conductor is heated the atoms in the metal vibrate with greater amplitude and frequency.
20. One kilowatt is equal to 10 horse power.
21. Fuse is a thin wire which melts and breaks the electric circuit due to only high voltage.

Match the Following :

DIRECTIONS : *Each question contains statements given in two columns which have to be matched. Statements (A, B, C, D) in **column I** have to be matched with statements (p, q, r, s) in **column II**.*

1. | Column I | Column II |
|---|---|
| (A) Ohm | (p) $\frac{\rho L}{A}$ |
| (B) Resistance | (q) $\frac{1\text{ volt}}{1\text{ ampere}}$ |
| (C) Resistivity | (r) zero resistance |
| (D) Super conductor | (s) ohm-meter |

2. In the figure shown, the value of each resistance is R. match the entries of column I with the entries of column II.



Column I	Column II
(A) Resistance between a and b	(p) $R/2$
(B) Resistance between a and c	(q) $\frac{5}{8}R$
(C) Resistance between b and d	(r) R

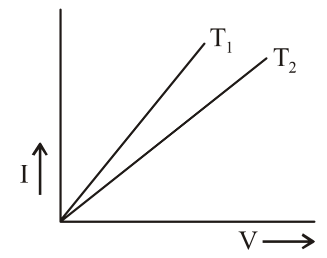
3. Column II gives name of material use for device given in column I

Column I	Column II
(A) Resistance of resistance box	(p) tungsten
(B) Fuse wire	(q) maganin
(C) Bulb	(r) tin-lead alloy
(D) Insulator	(s) glass

Very Short Answer Questions:

DIRECTIONS : *Give answer in one word or one sentence.*

1. What are the factors on which resistance depends?
2. Which combination have maximum value of equivalent resistance?
3. If one coulomb charge flows in a circuit for one second then what will be the value of current in the circuit.
4. Name the instrument used to measure electric current.
5. Manganin is used for making standard resistors. Why?
6. A wire of resistivity ρ is stretched to double its length. What will be its new resistivity?
7. A copper wire of resistivity ρ is stretched to reduce its diameter to half of its previous value. What will be its new resistivity?
8. Which physical quantity does the voltage vs current graph for a metallic conductor depict?
9. Specific resistance of copper, silver and constant an are $1.18 \times 10^{-6}\ \Omega$ cm, $1 \times 10^{-6}\ \Omega$ cm and $48 \times 10^{-6}\ \Omega$ cm respectively. Which is the best electrical conductor and why?
10. V-I graph for a metallic wire at two different temperatures T_1 and T_2 is as shown in the following figures. Which of the two temperature is higher and why?



11. What is the effect on current through a circuit of steady resistance when both voltage and resistance are doubled?
12. What happens to the force between two electric charges, if the distance between them is
(i) halved, (ii) doubled?
13. What is the actual direction of current and what is conventional direction?
14. What happens to the heat produced when current is doubled?
15. Name two devices which work on heating effect of electric current.
16. What is a fuse and specify its uses?
17. Define electric power and give its units in S.I.
18. What is the operating resistance of a 100-watt household light bulb ? The operating line voltage of household electricity is 120V.
19. Why does the cord of an electric heater not glow while the heating element does ?
20. How does the amount of current in a household circuit differ from the amount of current in a reading lamp?
21. Would you expect to find DC or AC in the filament of a light bulb in your home? How about in the headlight of an automobile?
22. A 220 volt 100 watts bulb is connected to 110 volts source, calculate the power consumed by the bulb.
23. An electric bulb is connected to a 220V generator. The current is 0.50V. What is the power of the bulb ?
24. What uses more energy, a 250 W TV set in 1 hr. or a 1200W toaster in 10 minutes ?

Short Answer Questions :

DIRECTIONS : *Give answer in 2-3 sentences.*

1. Write Ohm's law. Explain it by giving diagram of an electric circuit.

2. Write the expression for the equivalent resistance R of three resistors R_1, R_2 and R_3 joined in (i) parallel, (ii) series.

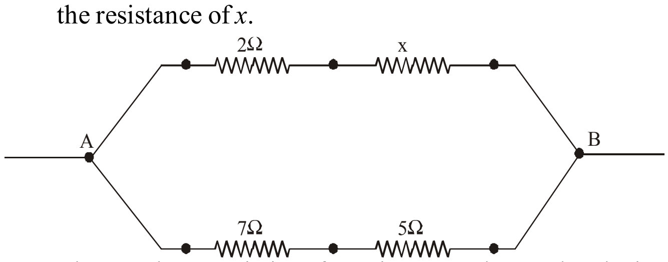
3. Define the term current and state its **S.I. unit.**

4. A lamp draws a current of 0.5A when it is connected to a 230 V supply. What is the resistance of the filament of the lamp?

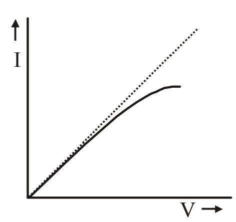
5. Join three resistances of 2 ohm each such that the total resistance of the circuit is 3 ohm.

6. Resistance of a metal wire of length 1m is 26Ω at 20°C. If the diameter of the wire is 0.3 mm, what will be the resistivity of the metal at that temperature.

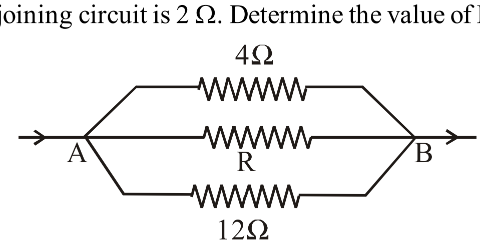
7. The equivalent resistance of circuit diagram is 4Ω. Calculate the resistance of *x*.



8. The *I-V* characteristics of a resistor are observed to deviate from a straight line for higher values of current as shown below. Why?



9. The equivalent resistance between the point A and B in the adjoining circuit is 2 Ω. Determine the value of R.



10. Obtain an expression for the (i) electrical energy (ii) electrical power, spent in flow of current through a conductor.

11. A 60W auto lamp allows 5 amps to pass through it. Find
(i) The p.d. across its terminal.
(ii) the resistance of the filament of the lamp
(iii) energy consumed in 2 hours

12. What is the electric power ? Derive a formula for it ?

13. An electric iron consumes energy at a rate of 840W when heating is at the maximum rate and 360W when the heating is at the minimum. The voltage is 220V. What are the current and the resistance in each case?

14. A geyser is rated 1500W, 250V. This geyser is connected to 250V mains. Calculate : (i) the current drawn, (ii) the energy consumed in 50 hours. (iii) the cost of energy consumed at ' 220 per kWh.

15. An electric iron of resistance 20Ω takes a current of 5A. Calculate the heat developed in 30s.

16. Compare the power used in the 2Ω resistor in each of the following circuits :
(i) a 6V battery in series with 1Ω and 2Ω resistors and (ii) a 4V battery in parallel with 12Ω and 2Ω resistors.

17. An electric heater of resistance 8Ω draws 15A from the service mains 2 hours. Calculate the rate at which heat is developed in the heater.

18. 100J of heat are produced each second in a 4Ω resistance. Find the potential difference across the resistor.

19. In the home electrical energy is converted into other energy forms. What is the energy conversion when
(a) an electric bell is used ?
(b) an electric toaster is used ?
(c) a fluorescent tube is switched on ?
(d) an electric fan is used ?

20. Two bulbs are marked 60 W, 220 V and 100 W, 220V. These are connected in parallel to 220 V main. Which one of the two will glow brighter ?

21. A toaster produces more heat than a light bulb when connected in a parallel to the 220 V mains. Which of the has greater resistance?

22. An electric heater is used everyday for 120 minutes. The electricity bill for 30 days is 60 units. Calculate the power of the electric heater.

23. In a household 5 tubelights of 40 W each are used for 5 hours and an electric press of 500 W for 4 hours everyday. Calculate the total electrical energy consumed by the tubelights and press in a month of 30 days.

24. A 100 W electrical bulb is lighted for 2 hours everyday and five 40 W tubes are lighted for 4 hours everyday. Calculate
(i) The energy consumed for 60 days and
(ii) Cost of electricity consumed at the rate of '1.50 per kWh.

25. What is meant by rating of electrical appliance?

26. What are the factors on which heat dissipated by a conductor depends?

27. Why is heat produced when a current is passed through a conductor?

28. Define one watt.

29. Why should the melting point of a fuse wire be low?

30. The filament of electric bulb is made of tungsten. Why?

31. State Ohm's law.

32. What is resistivity? Explain.

33. Give two reasons why are the conductors (filament) of electrical heating devices made of an alloy rather than a pure metal.

34. Establish the relation between kilowatt-hour and joules.

35. State the factors on which heat produced by an electric current passing through a conductor depends? Explain.

36. Give three applications of heating effect of electric current.

Long Answer Questions :

DIRECTIONS : *Give answer in 4 to 5 sentences.*

1. Explain how the resistance of the conductor vary if
(i) area is halved (ii) length is doubled
(iii) area is doubled
(iv) both area and length are doubled?

2. Draw the schematic diagram of circuit containing the following electrical components:
(i) a resistance (ii) a voltmeter
(iii) an electric bulb (iv) a cell
(v) plug key (open) (vi) an ammeter.

3. How does the resistance of a metallic wire depend on its temperature? Explain the reason to your answer.

4. A circuit consists of a 1Ω wire in series with a parallel arrangement of 6Ω and 3Ω with a P.D. of 12V is connected across the whole circuit. Draw the circuit diagram and calculate the main current in the circuit.

5. A copper wire has diameter 0.5 mm and resistivity of 1.6×10^{-8} Ωm. What will be the length of this wire to make its resistance 10Ω ? How much does the resistance change if the diameter is doubled ?

6. Three resistors of 20 ohm, 30 ohms and 50 ohm resistance are joined in series. Across this combination a source of 150 volts is connected then determine the current in each resistor and potential difference across their ends.

7. When a potential difference of 2 volt is applied across the ends of a wire of 5m length, a current of 1A is found to flow through it. Calculate :
(i) the resistance per unit length of the wire
(ii) the resistance of 2m length of this wire
(iii) the resistance across the ends of the wire it is doubled on itself.

8. How can three resistors of resistance 2Ω, 3Ω and 6Ω be connected to give a total resistance of 4?

9. A battery of 9V is connected in series with resistors of 0.2Ω, 0.3Ω, 0.4Ω, 0.5Ω and 12Ω respectively. How much current would flow through the 12Ω resistor?

10. Define resistivity of material. State its S.I. units and discuss its variation with temperature in case of (i) metals (ii) semiconductors and (iii) insulators.

11. What are the safety measures to be taken while dealing with household electricity?

12. Three 250 watt heaters are connected in parallel to a 100 volt supply. Calculate :
(i) the total current taken from the supply.
(ii) the resistance of each heater.
(iii) the energy supplied in kWh to the three heaters in 5 hours.

2 EXERCISE

Text-Book Questions :

1. What does an electric circuit means?
2. Define the unit of current.
3. Calculate the number of electrons constituting one coulomb of charge.
4. Name a device that helps to maintain a potential difference across a conductor.
5. What is meant by saying that the potential difference between two points is 1 V?
6. How much energy is given to each coulomb of charge passing through a 6 V battery?
7. On what factors does the resistance of a conductor depend?
8. Will current flow more easily through a thick wire or a thin wire of the same material, when connected to the same source? Why?
9. Let the resistance of an electrical component remain constant while the potential difference across the two ends of the component decreases to half of its former value. What change will occur in the current through it?
10. Why are coils of electric toasters and electric irons made of an alloy rather than a pure metal?
11. Answer the following.
    (a) Which is a better conductor among iron mercury?
    $\rho_{iron} = 10 \times 10^{-8}\,\Omega m$, $\rho_{mercury} = 94 \times 10^{-8}\,\Omega m$
    (b) Which material is the best conductor?
12. Draw a schematic diagram of a circuit consisting of a battery of three cells of 2V each. a 5 Ω resistor, an 8 Ω resistor, and a 12 Ω resistor, and a plug key. All connected in series.
13. Redraw the circuit of question 12, putting in an ammeter to measure the current through the resistors and a voltmeter to measure the potential difference across the 12Ω resistor. What would be the readings in the ammeter and the voltmeter?
14. Judge the equivalent resistance, when the following are connected in parallel (i) 1 Ω and 10^6 Ω (ii) 1 Ω and 10^3 Ω, and 10^6 Ω ?
15. An electric lamp of 100 Ω, a toaster of resistance 50 Ω, and a water filter of resistance 500 Ω are connected in parallel to a 220V source. What is the resistance of an electric iron connected to the same source that takes as much current as all three appliances, and what is the current through it?
16. What are the advantages of connecting electrical devices in parallel with the battery instead of connecting them in series ?
17. How can three resistors of resistances 2 Ω, 3 Ω and 6 Ω be connected to give a total resistance of
    (a) 4 Ω, (b) 1 Ω
18. What is (a) the highest and (b) the lowest total resistance that can be secured by combinations of four coils of resistance 4 Ω, 8 Ω, 12 Ω and 24 Ω?
19. Why does the cord of an electric heater not glow while the heating element does?
20. Compute the heat generated while transferring 96000 coulomb of charge in one hour through a potential difference of 50 V.
21. An electric iron of resistance 20 Ω takes a current of 5A. Calculate the heat developed in 30 sec.
22. What determines the rate at which energy is delivered by a current?
23. An electric motor takes 5A from a 220 V line. Determine the power of the motor and the energy consumed in 2 h.

Text-Book Exercise :

1. A piece of wire of resistance R is cut into five equal parts. These parts are then connected in parallel. If the equivalent resistance of this combination is R' then the ratio R/R' is
   (a) 1/25 (b) 1/5
   (c) 5 (d) 25
2. Which of the following terms does not represent electrical power in a circuit?
   (a) I^2R (b) IR^2
   (c) VI (d) V^2/R
3. An electric bulb is rated 220V and 100W. When it is operated on 110V, the power consumed will be –
   (a) 100 W (b) 75 W
   (c) 50 W (d) 25 W
4. Two conducting wires of the same material and of equal lengths and equal diameters are first connected in sereis and then in parallel in an electric circuit. The ratio of heat produced in series and in parallel combinations would be–
   (a) 1 : 2 (b) 2 : 1
   (c) 1 : 4 (d) 4 : 1
5. How is a voltmeter connected in the circuit to measure the potential difference between two points ?
6. A copper wire has diameter 0.5 mm and resistivity of 1.6×10^{-8} Ω m. What will be the length of this wire to make its resistance 10 Ω ? How much does the resistance change if the diameter is doubled ?
7. The values of current I flowing in a given resistor for the corresponding values of PD across the resistor are given below -

I (amperes)	0.5	1.0	2.0	3.0	4.0
V (volts)	1.6	3.4	6.7	10	13

   Plot a graph between V and I and calculate the resistance of that resistor.
8. When a 12V battery is connected across an unknown resistor, there is a current of 2.5 mA in the circuit? Find the value of the resistance of the resistor.

9. A battery of 9V is connected in series with resistors of 0.2 Ω, 0.3 Ω, 0.4 Ω, 0.5 Ω and 12 Ω respectively. How much current would flow through the 12 Ω resistor?

10. How many 176 Ω resistors (in parallel) are required to carry 5A on a 220 V line ?

11. Show how you would connect three resistors, each of resistance 6 Ω, so that the combination has a resistance of (i) 9 Ω, (ii) 4 Ω

12. Several electric bulbs designed to be used on a 220V electric supply line, are rated 10W. How many lamps can be connected in parallel with each other across the two wires of 220 V line if the maximum current is 5A ?

13. A hot plate of an electric oven connected to a 220 V line has two resistance coils A and B, each of 24 Ω resistance, which may be used separately, in series or in parallel. What are the currents in the three cases?

14. Compare the power used in the 2 Ω resistor in each of the following circuit. (i) a 6V battery in series with 1 Ω and 2 Ω resistors (ii) a 4V battery in parallel with 12 Ω and 2 Ω resistors.

15. Two lamps, one rated 100W at 220V, and the other 60W at 220V, are connected in parallel to electric mains supply. What current is drawn from the line if the supply voltage is 220V ?

16. Which uses more energy, a 250W TV set in 1hr, or a 1200W toaster in 10 minutes?

17. An electric heater of resistance 8 Ω draws 15A from the service mains in 2hrs. Calculate the rate at which heat is developed in the heater.

18. Explain the following.
   (a) Why is the tungsten used almost exclusively for filament of electric lamps?
   (b) Why are the conductors of electric heating devices, such as bread-toasters and electric irons made of an alloy rather than a pure metal?
   (c) Why is the series arrangement not used for domestic circuits?
   (d) How does the resistance of a wire vary with its area of cross-section?
   (e) Why are copper and aluminium wires usually employed for electricity transmission?

Exemplar Questions :

DIRECTIONS : *Answer the following questions.*

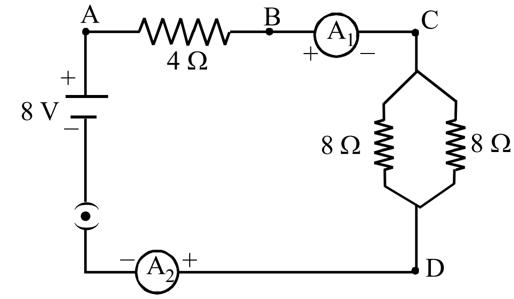
1. How does use of a fuse wire protect electrical appliances?

2. What is electrical resistivity? In a series electrical circuit comprising a resistor made up of a metallic wire, the ammeter reads 5 A. The reading of the ammeter decreases to half when the length of the wire is doubled. Why?

3. Why is parallel arrangement used in domestic wiring?

4. Three incandescent bulbs of 100 W each are connected in series in an electric circuit. In another circuit another set of three bulbs of the same wattage are connected in parallel to the same source.
   (i) Will the bulb in the two circuits glow with the same brightness? Justify your answer.
   (ii) Now let one bulb in both the circuits get fused. Will the rest of the bulbs continue to glow in each circuit? Give reason.

5. Find out the following in the electrical circuit given in figure.

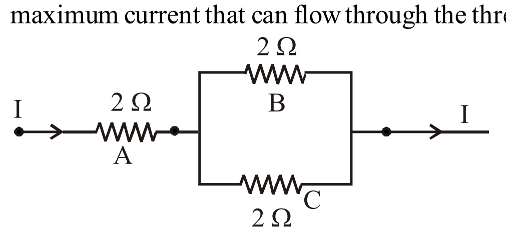


   (i) Effective resistance of two 8 Ω resistance in the combination
   (ii) Current flowing through 4 Ω resistor
   (iii) Potential difference across 4 Ω resistance
   (iv) Power dissipated in 4 Ω resistor
   (v) Difference in ammeter readings, if any.

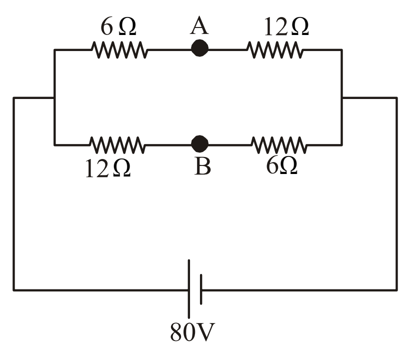
Hots Questions :

DIRECTIONS : *Answer the following questions.*

1. Three 2Ω resistors, A, B and C are connected as shown in Figure. Each of them dissipates energy and can withstand a maximum power of 18W without melting. Find the maximum current that can flow through the three resistors?



2. In the circuit shown, if a wire is connected between points A and B. How much current will flow through that wire?



3. A potential difference V is applied across a conductor of length L and diameter D. How the electric field E and resistance R effected when
   (i) V is halved   (ii) L is halved
   (iii) D is doubled
   Justify your answer in each case.

4. A cylinder of a material is 10 cm long and has a cross-section of $2cm^2$. If its resistance along the length be 20Ω, what will its resistivity value be in number and units?

5. Two wires, one of manganin and the other of copper have equal lengths and resistances. Which one of these wires will be thicker?

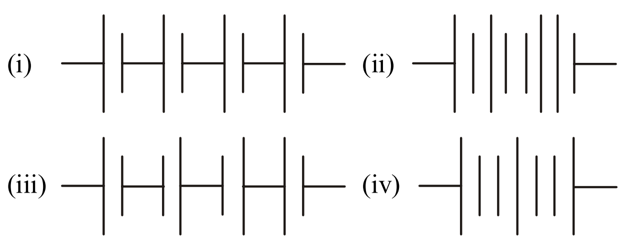
3 EXERCISE

Single Option Correct :

DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. A current of 1 A is drawn by a filament of an electric bulb. Number of electrons passing through a cross section of the filament in 16 seconds would be roughly
(a) 10^{20} (b) 10^{16}
(c) 10^{18} (d) 10^{23}

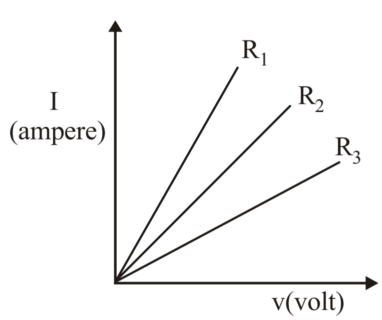
2. The proper representation of series combination of cells (Figure) obtaining maximum potential is



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

3. A cylindrical conductor of length l and uniform area of crosssection A has resistance R. Another conductor of length $2l$ and resistance R of the same material has area of cross section
(a) $A/2$ (b) $3A/2$
(c) $2A$ (d) $3A$

4. A student carries out an experiment and plots the V-I graph of three samples of nichrome wire with resistances R_1, R_2 and R_3 respectively (Figure). Which of the following is true?
(a) $R_1 > R_2 = R_3$ (b) $R_1 > R_2 > R_3$
(a) $R_3 > R_2 = R_1$ (b) $R_2 > R_3 > R_1$



5. An electric kettle consumes 1 kW of electric power when operated at 220 V. A fuse wire of what rating must be used for it?
(a) 1 A (b) 2 A
(c) 4 A (d) 5 A

6. A cylindrical rod is reformed to twice its length with no change in its volume. If the resistance of the rod was R, the new resistance will be
(a) R (b) $2R$
(c) $4R$ (d) $8R$

7. What is the current through a 5.0 ohm resistor if the voltage across it is $10V$
(a) zero (b) 0.50 A
(c) 2.0 A (d) 5.0 A

8. The length of a wire is doubled and the radius is doubled. By what factor does the resistance change
(a) 4 times as large (b) twice as large
(c) unchanged (d) half as large

9. A circular conductor is made of a uniform wire of resistance 2×10^{-3} ohm/metre and the diameter of this circular conductor is 2 metres. Then the resistance measured between the ends of the diameter is (in ohms)
(a) $\pi \times 10^{-3}$ (b) $2\pi \times 10^{-3}$
(c) $4\pi \times 10^{-3}$ (d) 4×10^{-3}

10. A 24V potential difference is applied across a parallel combination of four 6 ohm resistor. The current in each resistor is
(a) 1 A (b) 4 A
(c) 16 A (d) 36 A

11. Three resistances of 2, 3 and 5Ω are connected in parallel to a 10V battery of negligible internal resistance. The potential difference across the 3Ω resistance will be
(a) 2 V (b) 3 V
(c) 5 V (d) 10 V

12. Two unequal resistances are connected in parallel. Which of the following statement is true
(a) current in same in both
(b) current is larger in higher resistance
(c) voltage-drop is same across both
(d) voltage-drop is lower in lower resistance

13. You are given n identical wires, each of resistance R. When these are connected in parallel, the equivalent resistance is X. When these will be connected in series, then the equivalent resistance will be
(a) X/n^2 (b) n^2X
(c) X/n (d) nX

14. A piece of wire of resistance R is cut into five equal parts. These parts are then connected in parallel. If the equivalent resistance of this combination is R', then the ratio R/R' is
(a) 1/25 (b) 1/5
(c) 5 (d) 25

15. 2 ampere current is flowing through a conductor from a 10 volt emf source then resistance of conductor is
(a) 20 Ω (b) 5 Ω
(c) 12 Ω (d) 8 Ω

16. Charge on an electron is 1.6×10^{-19} coulomb. Number of electrons passing through the wire per second on flowing of 1 ampere current through the wire will be
(a) 0.625×10^{-19} (b) 1.6×10^{-19}
(c) 1.6×10^{-19} (d) 0.625×10^{19}

17. 20 coulomb charge is flowing in 0.5 second from a point in an electric circuit then value of electric current in amperes will be
(a) 10 (b) 40
(c) 0.005 (d) 0.05

18. Three resistors of 4.0 Ω, 6.0 Ω and 10.0 Ω are connected in series. What is their equivalent resistance
(a) 20 Ω (b) 7.3 Ω
(c) 6.0 Ω (d) 4.0 Ω

19. A letter 'A' is constructed of a uniform wire of resistance 1 ohm per cm. The sides of the letter are 20 cm and the cross piece in the middle is 10 cm long. The resistance between the ends of the legs will be
(a) 32.4 ohm (b) 28.7 ohm
(c) 26.7 ohm (d) 24.7 ohm

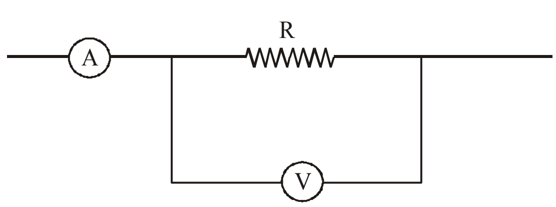
20. A wire of resistance R is cut into ten equal parts which are then joined in parallel. The new resistance is
(a) 0.01 R (b) 0.1 R
(c) 10 R (d) 100 R

21. If a wire is stretched to make its length three times, its resistance will become
(a) three times (b) one-third
(c) nine times (d) one-ninth

22. The resistivity of a wire depends on
(a) length
(b) area of cross-section
(c) material
(d) all the above three factors

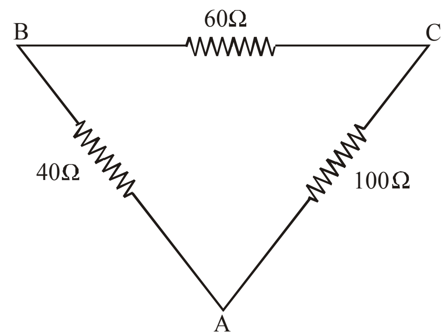
23. Ampere-second stands for the unit of
(a) power (b) charge
(c) e.m.f. (d) energy

24. In the circuits shown below the ammeter A reads 4 amp. and the voltmeter V reads 20 volts. The value of the resistance R is



(a) slightly more than 5 ohms
(b) slightly less than 5 ohms
(c) exactly 5 ohms
(d) None of the above

25. Three resistors are connected to form the sides of a triangle ABC as shown below.



The resistance of side AB is 40 ohms, of side BC 60 ohms and of side CA 100 ohms. The effective resistance between the point A and B in ohms is
(a) 50 (b) 64
(c) 32 (d) 100

26. If one micro-amp. current is flowing in a wire, the number of electrons which pass from one end of the wire to the other end in one second is
(a) 6.25×10^{12} (b) 6.25×10^{15}
(c) 6.25×10^{18} (d) 6.25×10^{19}

27. The unit for specific resistance is
(a) ohm × second (b) ohm × cm
(c) ohm (d) ohm/cm

28. If the temperature of a conductor is increased, its resistance will
(a) not increase
(b) increase
(c) decrease
(d) change according to the whether

29. The unit for electric conductivity is
(a) ohm per cm (b) ohm × cm
(c) ohm per second (d) mho

30. Two wires of resistance R_1 and R_2 are joined in parallel. The equivalent resistance of the combination is
(a) $R_1R_2/R_1 + R_2$ (b) $R_1 + R_2$
(c) $R_1 \times R_2$ (d) R_1/R_2

31. Gases are good conductors of electricity at
(a) high pressure (b) low pressure
(c) low temperature (d) high temperature

32. The resistance of a thin wire in comparison of a thick wire of the same material
(a) is low
(b) is equal
(c) depends upon the metal of the wire
(d) is high

33. If the specific resistance of a wire of length l and radius r is k then resistance is
(a) $k\pi r^2 / l$ (b) $\pi r^2 / lk$
(c) $kl / \pi r^2$ (d) k / lr^2

34. If a charge of 1.6×10^{-19} coulomb flows per second through any cross section of any conductor, the current constitute will be
(a) 2.56×10^{-19} A (b) 6.25×10^{-19} A
(c) 1.6×10^{-19} A (d) 3.2×10^{-19} A

35. The number of electrons flowing per second through any cross section of wire, if it carries a current of one ampere, will be
(a) 2.5×10^{18} (b) 6.25×10^{18}
(c) 12.5×10^{18} (d) 5×10^{18}

36. The number of electron passing through a heater wire in one minute, if it carries a current of 8 ampere, will be
(a) 2×10^{20} (b) 2×10^{21}
(c) 3×10^{20} (d) 3×10^{21}

37. The total momentum of electrons in a straight wire of length $\ell = 1000$ m carrying a current $I = 70$ A, will be (in N. s)
(a) 0.40×10^{-6} (b) 0.20×10^{-6}
(c) 0.80×10^{-6} (d) 0.16×10^{-6}

38. In a wire of length 4m and diameter 6mm, a current of 120 ampere is passed. The potential difference across the wire is found to be 18 volt. The resistance of wire will be
(a) 0.15 ohm (b) 0.25 ohm
(c) 6.660 ohm (d) none of the above

39. The resistance between two rectangular faces of a block of dimensions 4 cm × 4 cm × 10 cm of maganin ($r = 48 \times 10^{-8}$ ohm, m), will be
(a) 4.8 μ Ω (b) 3.8 μ Ω
(c) 30 μ Ω (d) 3 μ Ω

40. If resistance of a wire formed by 1.cc of copper be 2.46Ω. The diameter of wire is 0.32 mm, then the specific resistance of wire will be
(a) 1.59×10^{-6} ohm. cm (b) 2.32×10^{-6} ohm. cm
(c) 3.59×10^{-6} ohm. cm (d) 1.59×10^{-8} ohm. cm

41. A given piece of wire length ℓ, cross sectional area A and resistance R is stretched uniformly to a wire of length 2ℓ. The new resistance will be
(a) 2 R (b) 4 R
(c) R/2 (d) Remains unchanged

42. A given piece of wire of length ℓ, radius r and resistance R is stretched uniformly to a wire of radius (r/2). The new resistances will be
(a) 2 R (b) 4 R
(c) 8 R (d) 16 R

43. There are two wires of the same length and of the same material and radial r and $2r$. The ratio of their specific resistance is
(a) 1 : 2 (b) 1 : 1
(c) 1 : 4 (d) 4 : 1

44. Specific resistance of a wire depends on the
(a) length of the wire
(b) area of cross-section of the wire
(c) resistance of the wire
(d) material of the wire

45. The resistance of some substances become zero at very low temperature, then these substances are called
(a) good conductors (b) super conductors
(c) bad conductors (d) semi conductors

46. The resistance of wire is 20Ω. The wire is stretched to three time its length. Then the resistance will now be
(a) 6.67 Ω (b) 60 Ω
(c) 120 Ω (d) 180 Ω

47. When the resistance of copper wire is 0.1 Ω and the radius is 1 mm, then the length of the wire is (specific resistance of copper is 3.14×10^{-8} ohm × m)
(a) 10 cm (b) 10 m
(c) 100 m (d) 100 cm

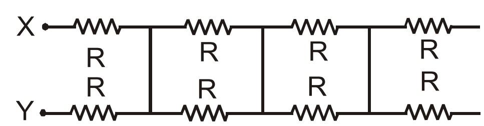
48. When the resistance wire is passed through a die the cross-section area decreases by 1%, the change in resistance of the wire is
(a) 1% decrease (b) 1% increase
(c) 2% decrease (d) 2% increase

49. Two wires of the same material having lengths in the ratio of 1 : 2 and diameters in the ratio 2 : 1 are connected with a cell of 6 volt and internal resistance 1Ω. The ratio of the potential difference across the two wires will be
(a) 1 : 2 (b) 2 : 1
(c) 1 : 8 (d) 8 : 1

50. The resistance $4R$, $16R$, $64R$, ...∞ are connected in series, their resultant will be
(a) 0 (b) ∞
(c) 4/3 R (d) 3/4 R

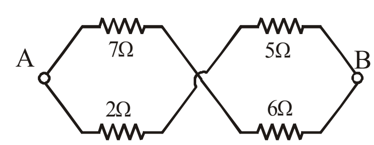
51. Resistance R, 2R, 4R, 8R .... ∞ are connected in parallel. Their resultant resistance will be
(a) R (b) R/2
(c) 0 (d) ∞

52. The equivalent resistance between points X and Y is



(a) R (b) 2R
(c) R/2 (d) 4 R

53. The equivalent resistance between points A and B is



(a) 4Ω (b) 4.5 Ω
(c) 2 Ω (d) 20 Ω

54. Three resistances 4Ω each of are connected in the form of an equilateral triangle. The effective resistance between two corners is
(a) 8Ω (b) 12Ω
(c) 3/8 Ω (d) 8/3 Ω

55. Two wires of same metal have the same length but their cross-sections area in the ratio 3 : 1. They are joined in series. The resistance of the thicker wire is 10Ω. The total resistance of the combination will be
(a) 40 Ω (b) 40/3 Ω
(c) 5/2 Ω (d) 100 Ω

56. A certain piece of silver of given mass is to be made like a wire. Which of the following combination of length (L) and the area of cross-sectional (A) will lead to the smallest resistance
(a) L and A (b) 2L and A/2
(c) L/2 and 2A
(d) Any of the above, because volume of silver remains same

57. A certain wire has a resistance R. The resistance of another wire identical with the first except having twice its diameter is
(a) 2 R (b) 0.25 R
(c) 4 R (d) 0.5 R

58. What length of the wire of specific resistance 48×10^{-8} Ω-m is needed to make a resistance of 4.2 Ω (diameter of wire = 0.4 mm)
(a) 4.1 m (b) 3.1 m
(c) 2.1 m (d) 1.1 m

59. The resistance of an ideal voltmeter is
(a) zero (b) very low
(c) very large (d) Infinite

60. Masses of 3 wires of same metal are in the ratio 1 : 2 : 3 and their lengths are in the ratio 3 : 2 : 1. The electrical resistances are in ratio
(a) 1 : 4 : 9 (b) 9 : 4 : 1
(c) 1 : 2 : 3 (d) 27 : 6 : 1

61. We have two wires A and B of same mass and same material. The diameter of the wire A is half of that B. If the resistance of wire A is 24 ohm then the resistance of wire B will be
(a) 12 ohm (b) 3.0 ohm
(c) 1.5 ohm (d) None of the above

62. The electric resistance of a certain wire of iron is R. If its length and radius are both doubled, then
(a) The resistance will be doubled and the specific resistance will be halved
(b) The resistance will be halved and the specific resistance will remain unchanged
(c) The resistance will be halved and the specific resistance will be doubled
(d) The resistance and the specific resistance, will both remain unchanged

63. When a wire of uniform cross-section a, length ℓ and resistance R is bent into a complete circle, resistance between any two of diametrically opposite points will be
(a) $R/4$ (b) $R/8$
(c) $4R$ (d) $R/2$

64. A solenoid is at potential difference 60V and current flows through it is 15 ampere, then the resistance of coil will be
(a) 4 Ω (b) 8 Ω
(c) 0.25 Ω (d) 2 Ω

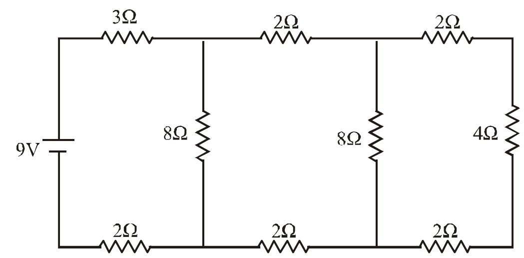
65. The resistance of a discharge tube is
(a) Ohmic (b) Non-ohmic
(c) Both (a) and (b) (d) Zero

66. Conductivity increases in the order of
(a) Al, Ag, Cu (b) Al, Cu, Ag
(c) Cu, Al, Ag (d) Ag, Cu, Al

67. By increasing the temperature, the specific resistance of a conductor and a semiconductor
(a) Increases for both (b) Decreases for both
(c) Increases, decreases (d) Decreases, increases

68. A strip of copper and another of germanium are cooled from room temperature to 80 K. The resistance of
(a) Each of these increases
(b) Each of these decreases
(c) Copper strip increases and that of germanium decreases
(d) Copper strip decreases and that of germanium increases

69. In the circuit shown in the figure, the current through



(a) the 3Ω resistor is 0.50A
(b) the 3Ω resistor is 0.25A
(c) the 4Ω resistor is 0.50A
(d) the 4Ω resistor is 0.25A

70. Which of the following has a negative temperature coefficient?
(a) C (b) Fe (c) Mn (d) Ag

71. Two electric lamps each of 100 watts 220V are connected in series to a supply of 220 volts. The power consumed would be –
(a) 100 watts (b) 200 watts
(c) 25 watts (d) 50 watts

72. If it takes 8 minutes to boil a quantity of water electrically, how long will it take to boil the same quantity of water using the same heating coil but with the current doubled
(a) 32 minutes (b) 16 minutes
(c) 4 minutes (d) 2 minutes

73. An electric bulb is filled with
(a) hydrogen (b) oxygen and hydrogen
(c) ammonia (d) nitrogen and argon

74. When current is passed through an electric bulb, its filament glows, but the wire leading current to the bulb does not glow because
(a) less current flows in the leading wire as compared to that in the filament
(b) the leading wire has more resistance than the filament
(c) the leading wire has less resistance than the filament
(d) filament has coating of fluorescent material over it

75. Which of the following terms does not represent electrical power in a circuit?
(a) I^2R (b) IR^2 (c) VI (d) V^2/R

76. Two conducting wires of the same material and of equal lengths and equal diameters are first connected in series and then parallel in a circuit across the same potential difference. The ratio of heat produced in series and parallel combinations would be
(a) 1:2 (b) 2:1 (c) 1:4 (d) 4:1

77. The filament of an electric bulb is of tungsten because
(a) Its resistance is negligible
(b) It is cheaper
(c) Its melting point is high
(d) Filament is easily made

78. When the current passes through the filament, it gets heated to incandescence and give light while the connecting wires are not heated because
(a) The connecting wires are good conductor of heat while the filament is bad conductor
(b) The connecting wires are of low resistance while the filament is of high resistance

(c) The density of connecting wires is less than that of the filament
(d) The connecting wires are bad conductor of heat while the filament is good conductor

79. Which one of the following heater element is used in electric press
(a) copper wire (b) nichrome wire
(c) lead wire (d) iron wire

80. What should be the characteristic of fuse wire?
(a) High melting point, high specific resistance
(b) Low melting point, low specific resistance
(c) High melting point, low specific resistance
(d) Low melting point, high specific resistance

81. The heating element of an electric heater should be made with a material, which should have
(a) high specific resistance and high melting point
(b) high specific resistance and low melting point
(c) low specific resistance and low melting point
(d) low specific resistance and high melting point

82. Resistance of conductor is doubled keeping the potential difference across it constant. The rate of generation of heat will
(a) become one fourth (b) be halved
(c) be doubled (d) become four times

83. A current I passes through a wire of length l, radius r and resistivity p. The rate of heat generated is
(a) $\frac{I^2\rho\ell}{r}$ (b) $\frac{I^2\rho\ell}{\pi r^2}$
(c) $\frac{I^2\rho\ell}{\pi r}$ (d) none of these

84. The resistance R_1 and R_2 are joined in parallel and a current is passed so that the amount of heat liberated is H_1 and H_2 respectively. The ratio H_1/H_2 has the value
(a) R_2/R_1 (b) R_1/R_2
(c) R_1^2/R_2^2 (d) R_2^2/R_1^2

More than One Option Correct :

DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

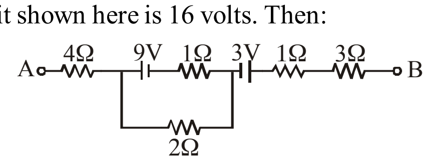
1. A current passes through a wire of non-uniform cross-section. Which of the following quantities are independent of the cross-section?
(a) The charge crossing in a given time interval
(b) Drift speed
(c) Current density
(d) Free-electron density

2. Two conductors made of the same material have lengths L and $2L$, but have equal resistances. The two are connected in series in a circuit in which current is flowing. Which of the following is/are correct?
(a) The potential difference across the two conductors is the same
(b) The electron drift velocity is larger in the conductor of length $2L$
(c) The electric field in the first conductor is twice than that in the second
(d) The electric field in the second conductor is twice than that in the first

3. When a potential difference is applied across the ends of a linear-metallic conductor:
(a) the free electrons are set in motion from their position of rest
(b) the free electrons are accelerated continuously from the lower potential end to the higher potential end of the conductor
(c) the free electrons acquire a constant drift velocity from the lower potential end to the higher potential end of the conductor
(d) the vibrating atomic ions in the conductor start vibrating more vigorously

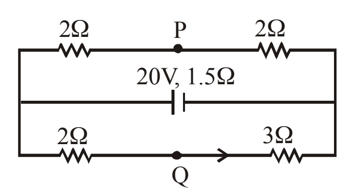
4. Electric current arises from the flow of charged particles. Now:
(a) in metals it is dominant due to flow of electrons
(b) in semiconductors it is jointly due to flow of holes and electrons
(c) in electrolytes it is due to flow of negative ions only
(d) in discharge tubes containing gases at low pressure it is due to flow of positive ions only

5. The potential difference between the points A and B in the circuit shown here is 16 volts. Then:



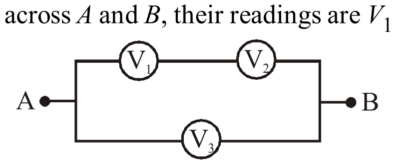
(a) the current through the 2Ω resistance is 3.5 amp
(b) the current through the 4Ω resistance is 2.5 amp
(c) the current through the 3Ω resistance is 1.5 amp
(d) the potential difference between the terminals of the 9V battery is 7V

6. In the given circuit:



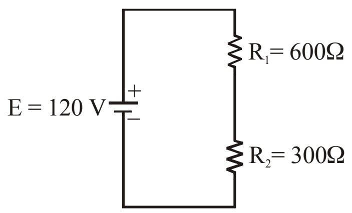
(a) the current through the battery is 5.0 amp
(b) P and Q are at the same potential
(c) P is 2.5 V higher than Q
(d) Q is 2.5 V higher than P

7. Three voltmeters, all having different resistances, are joined as shown in the figure. When some potential difference is applied across A and B, their readings are V_1, V_2, V_3:



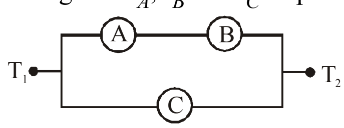
(a) $V_1 = V_2$ (b) $V_1 \neq V_2$
(c) $V_1 + V_2 = V_3$ (d) $V_1 + V_2 > V_3$

8. In the circuit, the battery is ideal. A voltmeter of resistance 600 Ω is connected in turn across R_1 and R_2, giving readings V_1 and V_2 respectively:



(a) $V_1 = 80$ V (b) $V_1 = 60$V
(c) $V_2 = 30$ V (d) $V_2 = 40$ V

9. Three ammeters A, B and C of resistances R_A, R_B and R_C respectively are joined as shown in the figure. When some potential difference is applied across the terminals T_1 and T_2, their readings are I_A, I_B and I_C respectively:



(a) $I_A = I_B$ (b) $I_A R_A + I_B R_B = I_C R_C$
(c) $\frac{I_A}{I_C} = \frac{R_C}{R_A}$ (d) $\frac{I_B}{I_C} = \frac{R_C}{R_A + R_B}$

10. A constant voltage is applied between the two ends of a uniform metallic wire. If both the length and radius of wire are doubled, then:
(a) the heat developed in the wire will be doubled
(b) the electric field in the wire will be doubled
(c) the heat developed will remain the same
(d) the electric field in the wire will be halved

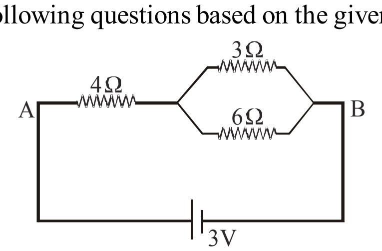
11. Two heaters designed for the same voltage V have different power ratings. When connected individually across a source of voltage V, they produce H amount of heat each in times t_1 and t_2 respectively. When used together across the same source, they produce H amount of heat in time t:
(a) if they are in series, $t = t_1 + t_2$
(b) if they are in series, $t = 2\,(t_1 + t_2)$
(c) if they are in parallel, $t = \frac{t_1 t_2}{(t_1 + t_2)}$
(d) if they are in parallel, $t = \frac{t_1 t_2}{2(t_1 + t_2)}$

Passage Based Questions :

DIRECTIONS : *Study the given paragraph(s) and answer the following questions.*

Passage -I

Answer the following questions based on the given circuit.



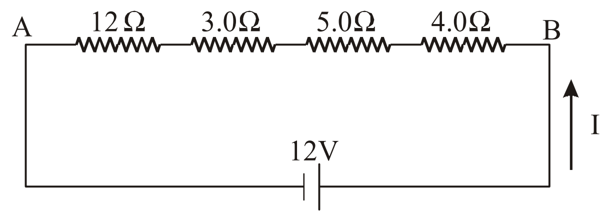
1. The potential drop across the 3Ω resistor is
(a) 1 V (b) 1.5 V
(c) 2 V (d) 3 V

2. The equivalent resistance between points A and B is
(a) 7Ω (b) 6Ω
(c) 13Ω (d) 5Ω

3. The current flowing through in the given circuit is
(a) 0.5 A (b) 1.5 A
(c) 6 A (d) 3 A

Passage -II

Answer the following questions based on the given circuit.



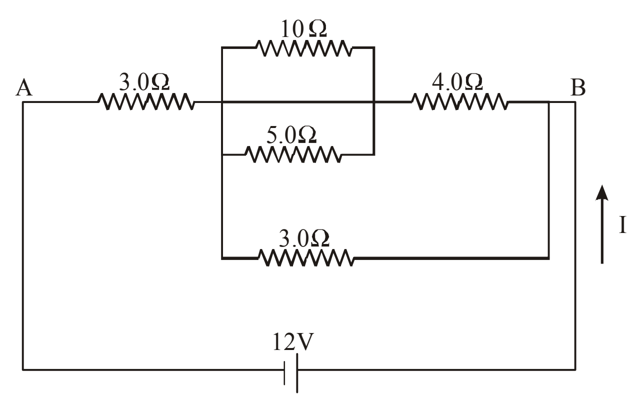
4. The equivalent resistance between points A and B, is
(a) 12 Ω (b) 36 Ω
(c) 32 Ω (d) 24 Ω

5. The current through each resistor is
(a) 1 A (b) 2.3 A
(c) 0.5 A (d) 0.75 A

6. The potential drop across the 12Ω resistor is
(a) 12 V (b) 6 V
(c) 8 V (d) 0.5 V

Passage -III

Answer the following questions based on the given circuit.



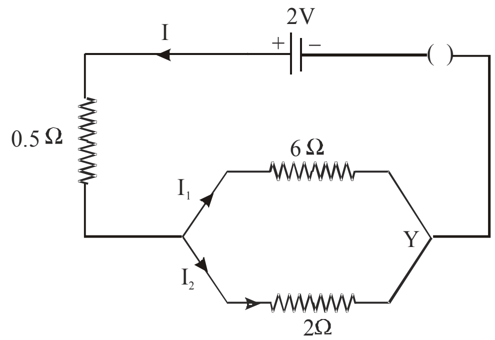
7. The equivalent resistance between points A and B
(a) 6.2 Ω (b) 5.1 Ω
(c) 13.33 Ω (d) 1.33 Ω

8. The current through the battery is
(a) 2.33 A (b) 3.12 A
(c) 4.16 A (d) 5.19 A

9. The current through the 4.0 ohm resistor is
(a) 5.6 A (b) 0.98 A
(c) 0.35 A (d) 0.68 A

Passage -IV

Answer the following questions based on the given circuit.



10. The total resistance of the circuit is
(a) 2 Ω (b) 4 Ω
(c) 1.5 Ω (d) 0.5 Ω

11. The current flowing through 0.5Ω resistor is
(a) 1 A (b) 1.5 A
(c) 3 A (d) 2.5 A

12. The current flowing through 6Ω resistor is
(a) 0.50 A (b) 0.75 A
(c) 0.80 A (d) 0.25 A

Passage-V

Two tungston lamps with resistances R_1 and R_2 respectively at full incandescence are connected first in parallel and then in series, in a lighting circuit of negaligible internal resistance. It is given that: $R_1 > R_2$.

13. Which lamp will glow more brightly when they are connected in parallel?
(a) Bulb having lower resistance
(b) Bulb having higher resistance
(c) Both the bulbs
(d) None of the two bulbs

14. If the lamp of resistance R_1 now burns out, how will the illumination produced change?
(a) Net illumination will increase
(b) Net illumination will decrease
(c) Net illumination will remain same
(d) Net illumination will reduced to zero

15. Which lamp will glow more brightly when they are connected in series?
(a) Bulb having lower resistance
(b) Bulb having higher resistance
(c) Both the bulbs
(d) None of the two bulbs

16. If the lampe of resistance R_2 now burns out and the lamp of resistance R_1 alone is plugged in, will the illumination increase or decrease?
(a) Illumination will remain same
(b) Illumination will increase
(c) Illumination will increase
(d) Illumination will decrease

17. Would physically bending a supply wire cause any change in the illumination?
(a) Illumination will remain same
(b) Illumination will increase
(c) Illumination will decrease
(d) It is not possible to predict from the given datas

Assertion & Reason :

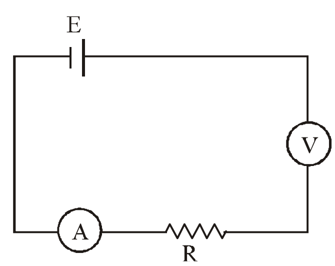
DIRECTIONS : *Each of these questions contains an Assertion followed by reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.
(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.
(c) If **Assertion** is **correct** but **Reason** is **incorrect**.
(d) If **Assertion** is **incorrect** but **Reason** is **correct**.

1. **Assertion :** When a battery is short-circuited, the terminal voltage is zero.
Reason : In the situation of a short-circuit, the current is zero

2. **Assertion :** The equation $V = Ri$ does not apply to those conducting devices which do not obey Ohm's law.
Reason : V = Ri is a statement of Ohm's law.

3. **Assertion :** All electric devices shown in the circuit are ideal. The reading of each of ammeter (a) and voltmeter (V) is zero.



Reason : An ideal voltmeter draws almost no current due to very large resistance, and hence (V) and (a) will read zero.

4. **Assertion :** If ρ_1 and ρ_2 be the resistivities of the materials of two resistors of resistances R_1 and R_2 respectively and $R_1 > R_2$, then $\rho_1 > \rho_2$.
Reason : The resistance $R = \rho\dfrac{\ell}{A} \Rightarrow \rho_1 > \rho_2$ if $R_1 > R_2$

5. **Assertion :** The product of resistivity and conductivity of a conductor depends on the material of the conductor.
Reason : Because each of resistivity and conductivity depends on the material of the conductor.

6. **Assertion :** Insulators do not allow flow of current through themselves.
Reason : They have no free-charge carriers.

7. **Assertion :** Positive charge inside the cell always goes from positive terminal to the negative terminal.
Reason : Positive charge inside the cell may go from negative terminal to the positive terminal.

8. **Assertion :** Wire A is thin in comparison to wire B of same material same length then resistance of wire A is greater than resistance of wire B.
Reason : Resistivity of wire A is greater than resistance of wire B.

9. **Assertion :** Resistivity of material may change with temperature.
Reason : Resistivity is a material property & independent on temperature.

10. **Assertion :** When current through a bulb decreases by 0.5%, the glow of bulb decreases by 1%.
Reason : Glow (Power) which is directly proportional to square of current.

11. **Assertion :** Long distance power transmission is done at high voltage.
Reason : At high voltage supply power losses are less.

12. **Assertion :** Resistance of 50W bulb is greater than that of 100 W.
Reason : Resistance of bulb is inversely proportional to rated power.

13. **Assertion :** 40 W tube light give more light in comparison to 40 w bulb.
Reason : Light produced is same from same power.

14. **Assertion :** A resistor of resistance R is connected to an ideal battery. If the value of R is decreased, the power dissipated in the circuit will increase.
Reason : The power dissipated in the circuit is directly proportional to the resistance of the circuit.

15. **Assertion :** A torch bulb give light if operated on AC of same voltage and current as DC.
Reason : Heating effect is common to both AC and DC.

16. **Assertion :** A tube light emits white light.
Reason : Emission of light in a tube takes place at a very high temperature

Multiple Matching Questions :

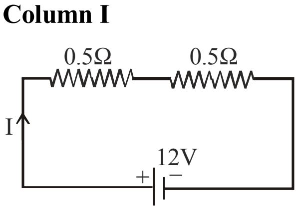
DIRECTIONS : *Following question has four statements (A, B, C and D) given in Column I and four statements (p, q, r and s) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

1.

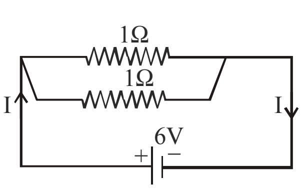
Column I	Column II
(A) Ohm's Law	(p) Direct proportional to area
(B) Resistivity	(q) Voltage α current
(C) For Ohmic-conductor	(r) $\frac{\text{charge}}{\text{time}}$
(D) Electric current	(s) $V = IR$

	A	B	C	D
(a)	q, s	p	q, s	r
(b)	p, q	q, s	r	q, r
(c)	p, s	q	r,s,t	r
(d)	p	q, r	r	r, s

2. **Column I** **Column II**

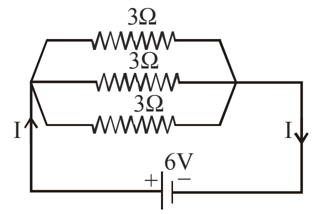
(A)


(p) $R_{eq} = 1\Omega, I = 12A$

(B)


(q) $\propto$ Length

(C) Resistance (r) $R_{eq} = 1\Omega, I = 6A$

(D)


(s) $\propto \frac{1}{\text{Area}}$

	A	B	C	D
(a)	p	p	s, q	r
(b)	p, q	q, s	r	q, r
(c)	p	p	s, q	r
(d)	s, r	r	p, q	r, s

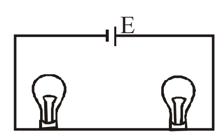
3.

Column I	Column II
(A) Ohm	(p) 1 Volt / 1 Amp
(B) Current	(q) Depends on matter of conductor
(C) Resistivity	(r) $\frac{\text{charge}}{\text{time}}$
(D) Super conductor	(s) $\frac{\text{Resistance}}{\text{Zero}}$

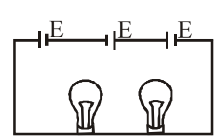
	A	B	C	D
(a)	p, r	p	r, s,	r
(b)	p	q, r	q	s
(c)	s, q	p, s	r	q
(d)	s, r	r	p, q	r, s

4. For the circuit shown in the adjoining figure, match the entries of column I with the entries of column II.

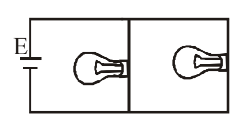
Column I **Column II**

(A)


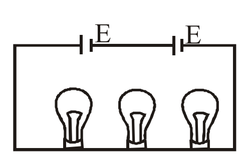
(p) Current drawn from the battery is maximum

(B)


(q) Current drawn from the battery is the least

(C)


(r) Bulbs will lit the brightest

(D)


(s) Bulbs will lit with brightness lying between maximum and minimum value

	A	B	C	D
(a)	q	r	p, s	s
(b)	p, q	q, s	r	q, r
(c)	s, r	r	p, q	r, s
(d)	p	p	s, q	r

Integer/ Numeric Questions :

DIRECTIONS : *Following are integer based/Numeric based questions. Each question, when worked out will result in one integer or numeric value.*

1. What is the number of electrons that would flow per second through the cross-section of a wire when 1 A current flows in it?

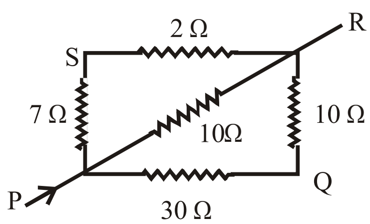
2. A current of 1.2 A flows through a conductor for 3.0 s. What amount of charge passes through the conductor?

3. Name a metal which offers higher resistance to the passage of electricity other than copper.

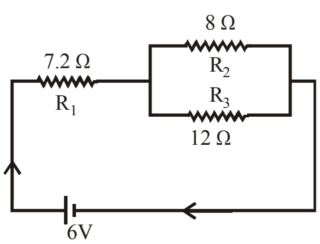
4. Two electric lamps rated 100 W, 220 V and 25 W, 220 V are connected in parallel to 220 V supply. Calculate the current in circuit.

5. A 3000 W immersion rod is connected to 240 V main supply. Calculate (i) current and (ii) resistance in circuit.

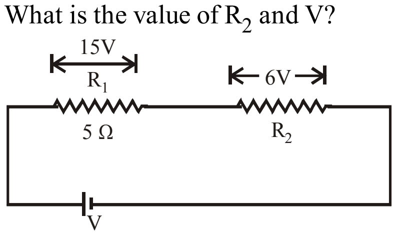
6. Find the equivalent resistance and total current in the circuit, if the point P and R are connected to a 6V battery.



7. In the circuit diagram find
(i) Total resistance of the circuit.
(ii) Total current flowing in the circuit.
(iii) Potential difference across R_1.



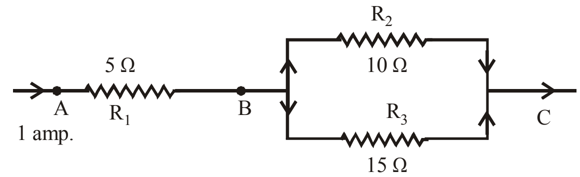
8. Two resistances are connected in series.
(i) Find current through 5 Ω resistance
(ii) What is the value of R_2 and V?



9. A potential difference of 250 volts is applied across a resistance of 500 ohms in an electric iron. Calculate (i) the current (ii) heat energy produce in joules in 10 secs?

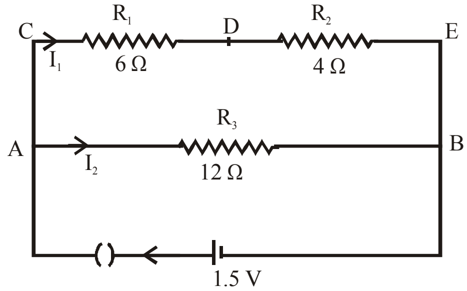
10. A 2000 W of electric geyser is used every day for 1 hour. How many units of electrical energy will it consume in 30 days?

11. Three resistors are connected as shown in the following figure. Through the resistor 5 ohm a current of 1 A is flowing.



(i) What is the total resistance?
(ii) What is the potential difference across AB and BC?
(iii) What is the current through other two resistors?

12. In the circuit shown in figure, calculate (i) the current flowing through the arms AB and CE; (ii) the potential difference across AB, CD and DE.



13. A copper wire has a diameter of 0.5 mm and resistivity of 16.2 ohm meter. How much of this wire would be required to make a 10 ohm coil?

14. Calculate the resistance of an aluminium wire of length 60 cm and cross-sectional area $1 mm^2$, the specific resistance of 2.6×10^{-8} Ωm?

15. Calculate the resistance of a conductor, if the current flowing through it is 0.2 A when the applied potential difference is 0.8 volt.

16. A student obtains resistances 3,4,12 and 16Ω using only two metallic resistance wires are either separately or joined together. What is the value of resistance of each of these wires?

17. A 60-W bulb is switched on in a room. A 240-W heater is also turned on in the same room. The voltage of the mains is 120V and the resistance of the connecting leads is 6Ω. What is the change in the voltage at the bulb when the heater is turned on.

18. A heater joined in parallel with a 60 W bulb is replaced by a 100 W bulb, Will the rate of heat produced by the heater be more or less or remains the same ?

19. Two bulbs whose resistances are in the ratio 1 : 2, are connected in parallel to a source of constant voltage. What will be the ratio of power dissipation of these?

20. In a factory, an electric bulb of 500 W is used for 2 hours and electric bulb of 500 W is used for 2 hours and electric motor of 0.5 horse power is used for 5 hours everyday. Calculate the cost of using the bulb and motor for 30 days if cost of electrical energy is three rupees per unit.

21. An electric lamp is marked 100 W, 220 V. It is used for 5 hours daily. Calculate
(i) its resistance while glowing
(ii) energy consumed in kWh per day.

22. A 60 W electric lamp gives off energy in the form of light at a rate of 7.5 joule per second. What percentage of energy does the lamp transform into light energy?

4 ADVANCED EXERCISE
BASED ON CONNECTING TOPICS

DIRECTIONS (Qs. 1-18): *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. When a 12Ω resistor is connected in series with a moving coil galvanometer then its deflection reduces from 50 divisions to 10 divisions. The resistance of the galvanometer is
(a) 24 ohm (b) 36 ohm
(c) 3 ohm (d) 60 ohm

2. In a Wheatstone's bridge all the four arms have equal resistance R. If the resistance of the galvanometer arm is also R, the equivalent resistance of the combination across the battery is
(a) $R/2$ (b) R
(c) $2R$ (d) $R/4$

3. Kirchoff's first law, i.e., $\Sigma\ i = 0$ at a junction, deals with the conservation of
(a) charge
(b) energy
(c) momentum
(d) angular momentum

4. If in the experiment of Wheatstone's bridge, the positions of cells and galvanometer are interchanged, then balance point will
(a) change
(b) remain unchanged
(c) depend on the internal resistance of cell and resistance of galvanometer
(d) None of these

5. In potentiometer a balance point is obtained, when
(a) the e.m.f. of the battery becomes equal to the e.m.f of the experimental cell
(b) the p.d. of the wire between the +ve end of battery to jockey becomes equal to the e.m.f. of the experimental cell
(c) the p.d. of the wire between +ve point of cell and jockey becomes equal to the e.m.f. of the battery
(d) the p.d. across the potentiometer wire becomes equal to the e.m.f. of the battery

6. In the experiment of potentiometer, at balance point, there is no current in the
(a) main circuit
(b) galvanometer circuit
(c) potentiometer circuit
(d) both main and galvanometer circuits

7. An electric bulb is rated 220V and 100W. When it is operated on 110V, the power consumed will be
(a) 100W (b) 75W
(c) 50W (d) 25W

8. From a power station, the power is transmitted at a very high voltage because –
(a) it is generated only at high voltage
(b) it is cheaper to produce electricity at high voltage
(c) electricity at high voltage is less dangerous
(d) there is less loss of energy in transmission at high voltage

9. On which one of the following the emf of a cell does not depend
(a) The nature of the metal of electrodes
(b) The size of the plates
(c) Nature of the electrolyte
(d) The nature of electrodes

10. The primary cell which is used in daily life is –
(a) Leclanche cell (b) Dry cell
(c) Daniel cell (d) Simple voltaic cell

11. Which one of the following primary cells has emf 1.08 volts and which remains fairly constant?
(a) Daniel cell (b) Simple voltaic cell
(c) Leclanche cell (d) Dry cell

12. If 10 cells each of 1.4 volts are connected in parallel, their equivalent potential difference will be
(a) 1.4 volts (b) 0.14 volts
(c) 14 volts (d) 10/1.4 volts

13. Two electric bulbs rated P_1 watt V volts and P_2 watt V volts are connected in parallel and applied across V volts. The total power (in watts) will be
(a) $P_1 + P_2$ (b) $\sqrt{P_1 P_2}$
(c) $\frac{P_1 P_2}{P_1 + P_2}$ (d) $\frac{P_1 + P_2}{P_1 P_2}$

14. If E be chemical equivalent of an element and Z is its electrochemical equivalent, then E/Z is measured in
(a) farad (b) newton
(c) coulomb (d) faraday

15. A silver and a zinc voltameter are connected in series and a current I is passed through them for a time t, liberating W grams of zinc. The weight of silver deposited is nearly
(a) 1.7 W grams (b) 2.4 W grams
(c) 3.5 W grams (d) 1.2 W grams

16. What determines the e.m.f. between the two metals placed in an electrolyte?

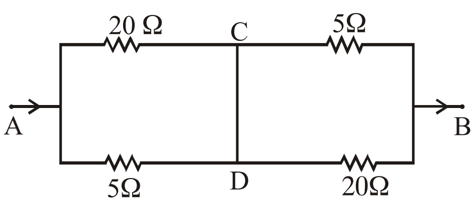
(a) relative position of metals in the electro chemical series
(b) distance between them
(c) strength of electrolyte
(d) nature of electrolyte

17. Faraday's laws are consequence of conservation of
(a) energy (b) energy and magnetic field
(c) charge (d) magnetic field

18. According to Faraday's law of electrolysis, the amount of decomposition is proportional to
(a) 1/time for which current passes
(b) electrochemical equivalent of the substance
(c) 1/current
(d) 1/electrochemical equivalent

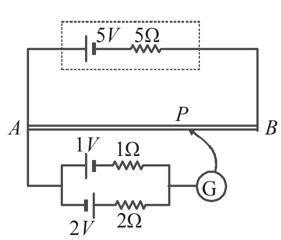
DIRECTIONS (Qs. 19-24) : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

19. When some potential difference is maintained between A and B, current I enters the network at A and leaves at B:



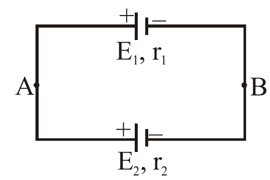
(a) the equivalent resistance between A and B is 8Ω
(b) C and D are at the same potential
(c) no current flows between C and D
(d) current $(3I/5)$ flows from D to C

20. A battery of emf $E_0 = 5V$ and internal resistance 5Ω is connected across a long uniform AB of length 1 m and resistance per unit length 5 Ω m^{-1}. Two cells of E_1 = 1 V and E_2 = 2V are connected as shown in the figure. :



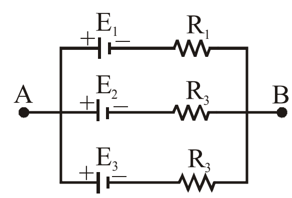
(a) The null point is at A
(b) If jockey is touched to point B the current in the galvanometer will be going towards B
(c) When jockey is connected to point A no current is flowing through 1 V battery.
(d) The null point is at distance of 8/15 m from A

21. Two cells of unequal e.m.fs. E_1 and E_2 and internal resistances r_1 and r_2 are joined as shown. V_A and V_B are the potentials at A and B respectively:



(a) one cell will continuously supply energy to the other
(b) the potential difference across both the cells will be equal
(c) the potential difference across one cell will be greater than its e.m.f.
(d) $V_A - V_B = \dfrac{(E_1 r_2 + E_2 r_1)}{(r_1 + r_2)}$

22. For the battery shown in the figure:



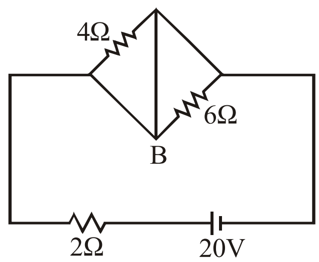
(a) equivalent internal resistance R is given by:

$$\frac{1}{R} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

(b) if $E_3 = \dfrac{(E_1 R_2 + E_2 R_1)}{(R_1 + R_2)}$, equivalent e.m.f. of the battery will be equal to E_3
(c) equivalent e.m.f. of the battery is equal to $E = (E_1 + E_2 + E_3)/3$
(d) equivalent e.m.f. of the battery not only depends upon values of E_1, E_2 and E_3 but depends upon values of R_1, R_2 and R_3 also

23. In a household electric circuit:
(a) all electric appliances drawing power are joined in parallel
(b) a switch may be either in series or in parallel with the appliance which it controls
(c) if a switch is in parallel with an appliance, it will draw power when the switch in the off position (open)
(d) if switch is in parallel with an appliance, the fuse will blow (burn out) when the switch is put on (closed)

24. In the circuit shown in the fiugre:

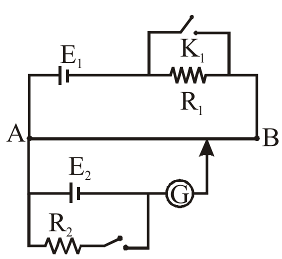


(a) power supplied by the battery is 200 watt
(b) current flowing in the circuit is 5A
(c) potential difference across 4Ω resistance is equal to the potential difference across 6Ω resistance
(d) current in wire AB is zero

DIRECTIONS (Qs. 25-28) : *Study the given paragraph(s) and answer the following questions.*

Passage

Figure shows the circuit of a potentiometer. The length of the potentiometer wire AB is 50 cm. The emf of the battery resistances R_1 and R_2 are 15 ohm and 5 ohm respectively. When both the keys are open, the null point is obtained at a distance of 31.25 cm from end A but when both the keys are closed, the balance length reduces to 5 cm only. Given $R_{AB} = 10\Omega$.



25. The emf of the cell E_2 is:
(a) 1 volt (b) 2 volt
(c) 3 volt (d) 4 volt

26. The internal resistance of the cell E_2 is:
(a) 4.5 Ω (b) 5.5 Ω
(c) 6.5 Ω (d) 7.5Ω

27. The balance length when key K_2 is open and K_1 is closed, is given by:
(a) 10.5 cm (b) 11.5 cm
(c) 12.5 cm (d) 13.5 cm

28. The balance length when key K_1 is open and K_2 is closed, is given by:
(a) 10.5 cm (b) 11.5 cm
(c) 12.5 cm (d) 13.5 cm

DIRECTIONS (Qs. 29-31) : *Each of these questions contains an Assertion followed by reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.
(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.
(c) If **Assertion** is **correct** but **Reason** is **incorrect**.
(d) If **Assertion** is **incorrect** but **Reason** is **correct**.

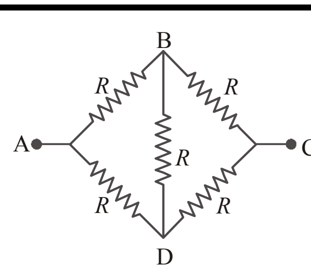
29. **Assertion :**
Kirchoff's junction rule follows from conservation of charge.
Reason : Kirchoff's loop rule follows from conservation of momentum.

30. **Assertion :** 40 W tube light give more light in comparison to 40 w bulb.
Reason : Light produced is same from same power.

31. **Assertion :** A resistor of resistance R is connected to an ideal battery. If the value of R is decreased, the power dissipated in the circuit will increase.
Reason : The power dissipated in the circuit is directly proportional to the resistance of the circuit.

DIRECTIONS (Q. 32): *Following question has four statements (A, B, C and D) given in Column I and 5 statements (p, q, r, s and t) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

32. Consider a network of resistances each of value of R as shown in figure.

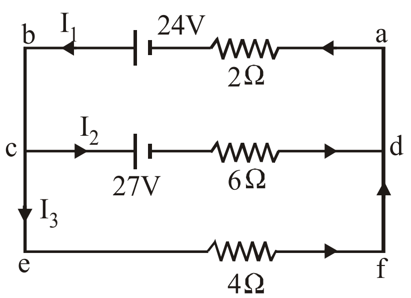


Column I	**Column II**
(A) Equivalent of net work between A and C is	(p) same
(B) Equivalent resistance between A an B	(q) 5/8 R
(C) Potential of B and D when voltage source is applied across A and C is	(r) R
(D) Potential of B and D when voltage source is applied across A and B is	(s) 2 R
	(t) different

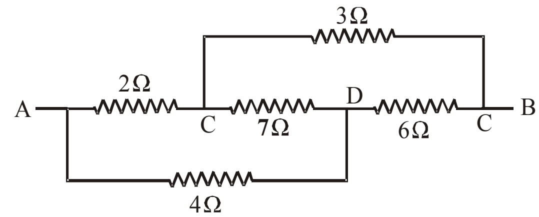
	A	B	C	D
(a)	r	q	p	t
(b)	s	p	q	r, t
(c)	p	s	r,s	q
(d)	s	q,r	r	s,t

DIRECTIONS (Qs. 33-37): *Following are integer based/ Numeric based questions. Each question, when worked out will result in one integer or numeric value.*

33. Determine currents I_1, I_2 and I_3?



34. Calculate the effective resistance between A and B in the following network.



35. In a meter bridge the length of wire is 100 cm. At what point is balance point obtained, if two resistances are in ratio of 2 : 3?

36. Two bulbs whose resistances are in the ratio 1 : 2, are connected in parallel to a source of constant voltage. What will be the ratio of power dissipation of these?

37. A heater coil is rated 100 W, 200 V. It is cut into two identical parts. Both parts are connected together in parallel to the same source of 200V.Calculate the energy liberated per second in the new combination.

SOLUTIONS

Brief Explanations of Selected Questions

1 EXERCISE

Fill in the Blanks :

1. current
2. zero
3. series
4. potential difference
5. resistivity
6. ampere
7. Resistance
8. ohm (Ω)
9. directly proportional, temperature
10. length, area of cross-section, material
11. joule
12. Scalar
13. decreases
14. ohm-meter
15. electric current
16. 1 Ω
17. inversely.
18. power, energy
19. ampere, hour
20. resistance, melting point
21. low, lead, tin, melts
22. series, live
23. separation
24. voltmeter
25. V × I × t
26. watt (W)
27. 1 V
28. 3,600,000 J
29. Tungsten
30. voltage, current
31. electric power

True / False :

1.	True	**2.**	False	**3.**	False	**4.**	True
5.	False	**6.**	True	**7.**	True	**8.**	True
9.	False	**10.**	False	**11.**	True	**12.**	True
13.	False	**14.**	False	**15.**	False	**16.**	True
17.	True	**18.**	True	**19.**	True	**20.**	False
21.	False						

Match the Following :

1. (A) → q; (B) → p; (C) → s; (D) → r
2. (A) → q;, (B) → p; (C) → r;
3. (A) → q; (B) → r; (C) → p; (D) → s

Very Short Answer Questions :

1. Resistance depends on: (i) temperature (ii) length and area of cross-section (iii) material of the conductor.

4. Ammeter

5. Manganin is an alloy whose temperature coefficient of resistance is almost negligible. So its resistance does not change with change in temperature, that is why it is used in making standard resistors.

6. Resistivity will not change as it depends on the material not on the length.

7. Resistivity will not change as it depends on the material not on the diamater of the wire.

8. Slope of voltage vs. current graph gives resistance of a metallic conductor. S.I. unit is ohm.

9. The specific resistance of silver is least. So it is the best conductor as the conductivity is the reciprocal of specific resistance.

10. Resistance increases with increase in temperature. Resistance of metallic wire is the inverse of slope of the graph R is more at $T_2 \therefore T_2 > T_1$.

11. If both voltage and resistance are doubled, there will be no change in the current.

12. (i) It becomes four times
 (ii) It becomes one fourth.

13. Actually, current flows from negative to positive terminal but conventionally, it is shown by positive to negative terminal.

14. It becomes four times.

15. (i) Electric toaster
 (ii) Electric heater.

16. Fuse is a thin wire which melts and breaks the electric circuit due to (i) overloading (ii) short circuit (iii) fluctuation in power supply.

17. The rate at which electric work is done is called electric power. In S.I., power = watt = 1 Js^{-1}.

18. Given : $P = 100$ W, V = 120 V, Find R.

 From $P = \dfrac{V^2}{R}$, We have $R = \dfrac{V^2}{P} = \dfrac{(120V)^2}{100W} = 144\ \Omega$

19. The cord of the electric heater made of copper does not glow because negligible heat is produced in it by passing current. It is due to its extremely low resistance.

20. The amount of current in a household circuit is more than the amount of current in a reading lamp as the current of the circuit is divided among all the appliances in a parallel household circuit.

21. There is AC flowing in the filament of the light bulb in our homes but DC flows in the bulbs of automobiles.

22. Resistance of the bulb

 $$R = \frac{V}{I} = \frac{V^2}{IV} = \frac{V^2}{W} \quad \text{or} \quad R = \frac{220 \times 220}{100} = 484 \text{ ohm.}$$

 Power consumed when connected to 110 volt source.

 $$= \frac{V^2}{R} = \frac{110 \times 110}{484} = 25 \text{ watt.}$$

23. P = VI = 220V × 0.50 A = 110 J/s = 110 W

24. 250W TV set in 1 hour.

Short Answer Questions :

1. Ohm's law:

4. $I = 0.5\ A,\ V = 230$ volt

$$R = \frac{V}{I} = \frac{230}{0.5} = 460\ \Omega$$

5. Two resistance in parallel, and the third in series with them.

6. We are given the resistance R of the wire = 26Ω, the diameter $d = 0.3$ mm $= 3 \times 10^{-4}$ m and the length ℓ of the wire = $1m$

We know that the resistivity of the given metallic wire is

$$\rho = \left(\frac{RA}{\ell}\right) = \left(\frac{R\pi d^2}{4\ell}\right)$$

$$= \frac{26 \times 22 \times 3 \times 10^{-4} \times 3 \times 10^{-4}}{7 \times 4 \times 1} = 183.857 \times 10^{-8}$$

$= 1.84 \times 10^{-8}\ \Omega$m

The resistivity of the metal at 20°C is $1.84 \times 10^{-8}\ \Omega$m

7. Equivalent resistance of circuit $R = 4\Omega$.

Equivalent resistance of 2Ω and x in series

$R_1 = 2\Omega + x$ .... (a)

Equivalent resistance of 7Ω and 5Ω in series

$R_2 = 7 + 5 = 12\Omega$.

As R_1 and R_2 are in parallel

$$\therefore \frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} \Rightarrow \frac{1}{4} = \frac{1}{R_1} + \frac{1}{12}$$

$$\therefore \frac{1}{R_1} = \frac{1}{4} - \frac{1}{12} = \frac{2}{12} = \frac{1}{6}$$

Putting value of R_1 in (a)

$6 = 2 + x \qquad \therefore x = 6 - 2 = 4\ \Omega$.

8. For higher current there are higher heat or energy losses as

$V = I^2 R$

9. $6\ \Omega$

11. (i) Power, $P = V \times I$

$60 = V \times I$

$$V = \frac{60}{5} = 12 \text{ volts}$$

(ii) Resistance = $R = \frac{V}{I} = \frac{12}{5} = 2.4\ \Omega$

(iii) Energy consumed in 2 hours

$$= \frac{\text{watts}}{1000} \times \text{hr} = \frac{60}{1000} \times 2 = 0.12 \text{ kWh}$$

13. We know that the power input is, $P = VI$

Thus the current I = P/V

(a) When heating is at the maximum rate,

$I = 840$ W/220V = 3.82 A

and the resistance of the electric iron is

$R = V/I = 220V/3.82\ A = 57.60\ \Omega$.

(b) When heating is at the minimum rate,

$I = 360$ W/220V = 1.64 A

and the resistance of the electric iron is

R = V/I = 220V/1.64 A = 134.15 Ω.

14. (i) 6A (ii) 75 kWh (iii) ' 165

15. Here, $R = 20\Omega,\ I = 5A,\ t = 30$s

Heat developed = $I^2Rt = 5 \times 5 \times 20 \times 30 = 15{,}000$ J = 15 kJ

16. (i) Equivalent resistance of 1Ω and 2Ω in series,

$R = 1\Omega + 1\Omega = 3\Omega$

Potential difference, $V = 6V$, Current, $I = \frac{V}{R} = \frac{6}{3} = 2A$

Current in series circuit is same.

$\therefore$ Current in 2Ω resistor = $2A$

Power in 2Ω resistor, $P = I^2R = 2^2 \times 2 = 8$W

(ii) Potential difference across 2Ω resistor = 4V

$$\text{Power, } P' = \frac{V^2}{R} = \frac{4^2}{2} = 8\text{W}$$

$P : P' = 8\text{W} : 8\text{W} = 1 : 1$

17. Here, $R = 8\Omega$, $I = 15A$, $t = 2h = 2 \times 60 \times 60$s

Heat developed, $H = I^2Rt = (15)^2 \times 8 \times 2 \times 60 \times 60$ J

The rate at which heat is developed is power.

$$\text{Power} = \frac{\text{Heat developed } (I^2Rt)}{\text{Time taken (t)}}$$

$$= \frac{15 \times 15 \times 8 \times 2 \times 60 \times 60}{2 \times 60 \times 60} = 1800 \text{ J/s}$$

18. $H = 100$ J, $R = 4$, $t = 1$s, V = ?

We have the current through the resistor as

$$I = \sqrt{H/Rt} = \sqrt{[100J/(4\Omega \times 1s)]} = 5A$$

Thus the potential difference across the resistor V is given by $V = IR = 5A \times 4\Omega = 20$V

19. (a) electrical $\to$ sound (b) electrical sound

(c) electrical $\to$ light (d) electrical $\to$ mechanical energy

20. 100 W bulb as $P \propto \frac{1}{R}$, i $\propto$ R (V is constant)

21. Since, $R \propto \frac{I}{P}\left(= \frac{V^2}{P}\right)$ toaster will have low resistance and bulb will have high resistance

22. Energy consumed in 30 days = 60 units

$$\text{(i.e)}, \frac{\text{days} \times \text{watt} \times \text{hours}}{1000} = 60$$

$$\Rightarrow \frac{30 \times P \times 2}{1000} = 60 \ ; \ P = 1000 \text{ watt.}$$

23. Energy consumed by five tubelights of 40 W for 5 hours in

$$1 \text{ day} = \frac{40}{1000} \times 5 = 1 \text{ kWh}$$

Energy consumed by an electric press of 500W for 4 hours

$$\text{in 1 day} = \frac{500 \times 4}{1000} = 2 \text{ kWh}$$

Energy consumed in 1 day = 1 + 2 = 3 kwh

$\therefore$ Total electrical energy consumed in 30 days
= 3 × 30 = 90 kWh = 90 units

24. (i) Energy consumed in days
= 100 × 2 × 60 + 5 × 40 × 4 × 60
= 12000 + 48000 = 60000 wh = 60 kWh

(ii) Cost of electricity = ₹ 1.50 × 60 = ₹ 90

25. It is the product of the voltage and the current which can flow through the device.

26. Heat dissipated depends upon (*i*) the square of current through the conductor (*ii*) the resistance of the conductor and (*iii*) the time for which current is passed.

27. During their motion the electrons collide with one another and hence lose some kinetic energy. This loss in kinetic energy is dissipated as heat across the conductor.

28. The power expended by a source is said to be 1 watt if one ampere of current flows through it under a potential difference of 1 volt.

29. So that it melts and breaks the circuit as soon as the safe limit of current is exceeded.

30. Because it has a high melting point and a high resistivity and does not easily react with air.

31. According to Ohm's law, "At a constant temperature the current flowing through a conductor is directly proportional to potential difference across its ends".

i.e., $V \propto I$

$V = RI$

'R' is a constant called resistance.

32. It is the resistance offered by a conductor of length 1 m and area of cross-section 1 m^2. It is also defined as the resistance offered by a cube of material of side 1 m, when current flows perpendicular to the opposite faces. It is measured in ohm-m. It is given by

$$\rho = \frac{RA}{L}$$

where, ρ = resistivity, R = resistance, A = area of cross-section, L = length of conductor.

33. (i) alloy has high resistivity.

(ii) alloy does not burn (oxidise) easily (i.e., high melting point).

34. 1 Kilowatt-hour = 1000 watt × 1 hour
= 1000 watt × 3600 sec.
= 3.6×10^6 watt - sec = 3.6×10^6 joules.

35. Heating effect of electric current depends on

(i) **Current :** Heat produces by an electric current is directly proportional to the square of magnitude of current, i.e., $H \propto I^2$

(ii) **Resistance :** Heat produced in a conductor by electric current is directly proportional to the resistance,

$$H \propto R$$

(iii) **Time :** It is directly proportional to the time for which current flows.

$$H \propto t.$$

36. (i) It is used in toaster, irons, ovens, etc.

(ii) It is used in heat convertors and filaments of electric bulbs.

(iii) It is used in fuse wires.

Long Answer Questions :

1. We know that,

$$R = \rho\frac{L}{A}$$

(i) If $A' = \frac{A}{2}$ then

$$R' = \rho\frac{L}{\frac{A}{2}}$$

$$R' = 2R$$

(ii) If $L' = 2L$ then

$$R' = \rho\frac{2L}{A}$$

$$R' = 2R$$

(iii) If $A' = 2A$ then

$$R' = \rho\frac{L}{2A}$$

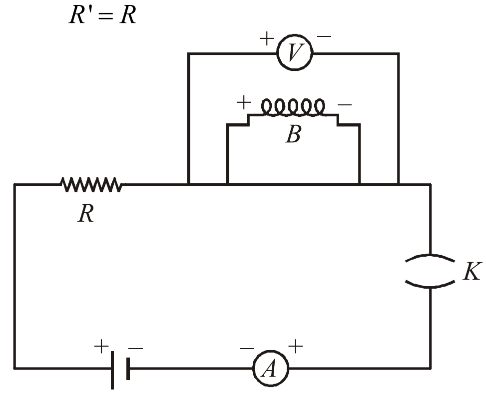
$$R' = \frac{R}{2}$$

(iv) If $A' = 2A, L' = 2L$ then

$$R' = \rho\frac{2L}{2A}$$

$$R' = R$$

2.



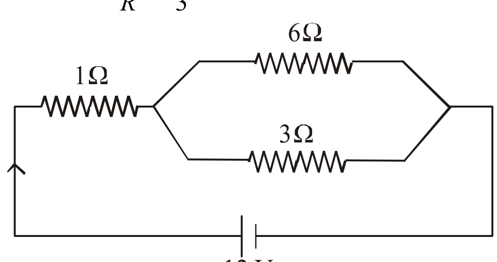
4. Effective resistance in the parallel circuit is

$$\frac{1}{R_1} = \frac{1}{6} + \frac{1}{3} = \frac{1+2}{6} = \frac{3}{6} = \frac{1}{2}$$

$\Rightarrow \quad R_1 = 2\,\Omega$

Total resistances $R = 1 + 2 = 3\Omega$

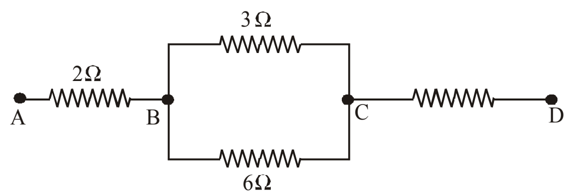
Current $I = \frac{V}{R} = \frac{12}{3} = 4A$



6. 1.5 ampere, 30 volts, 45 volts, 75 volts

7. (i) 0.4 Ωm^{-1} (ii) 0.8 Ω (iii) 1

8. As the total resistance (equivalent resistance) is 4Ω, the 6Ω resistor cannot be in series. So, it must be in parallel with some other resisters.



In parallel connection, the equivalent resistance (4Ω) has to be less than all the resistances. So, the resistors of 2Ω and 3Ω cannot be in parallel at one time with 6Ω.

So, the resistors have to be in a mixed combination. Let us consider the combination show in the figure.

The equivalent resistance between B and C (which are in parallel) $= \dfrac{3\Omega \times 6\Omega}{3\Omega + 6\Omega} = \dfrac{18\Omega}{9\Omega} = 2\Omega$

The resistance between A and $D = 2\Omega + 2\Omega = 4\Omega$.

So, the combination shown in the figure is true.

9. Resistors are connected in series.

So, equivalent resistance

$$R = 0.2\ \Omega + 0.3\ \Omega + 0.4\ \Omega + 0.5\ \Omega + 12\ \Omega = 13.4\ \Omega.$$

Potential difference, $V = 9V$

Current, through the circuit, $I = \dfrac{V}{R} = \dfrac{9}{13.4} = 0.67\ A$

10. The resistivity of the material of a conductor is defined as the resistance of unit length and unit area of cross–section of the conductor. The S.I. unit of resistivity is ohm metre (Ωm).

Resistivity of a material,

$\rho = \dfrac{m}{ne^2\tau}$ or $\rho \alpha \dfrac{1}{n\tau}$ Where m is the mass of electron, n is the number density of electron and τ is the average relaxation time. This shows that the resistivity is related to two parameters of the material namely n and τ.

The variation of resistivity with temperature is different in different materials.

(a) **For metallic conductors**

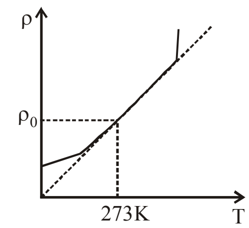
The temperature dependence of resistivity of a metal is given by the relation,

$$\rho = \rho_0[1 + \alpha(T - T_0)] \qquad \text{.............(1)}$$

Where ρ and ρ_0 are the resistivity at temperature T and T_0 respectively and α is called temperature coefficient of resistivity.

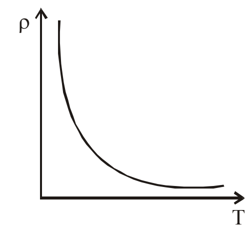
$$\therefore \quad \alpha = \frac{\rho - \rho_0}{\rho_0(T - T_0)} = \frac{d\rho}{\rho_0}.\frac{1}{dT} \qquad \text{...........(2)}$$

The resistivity of a conductor increases with increase in temperature since α is positive. The variation of resistivity of copper with temperature is as shown.



(b) **For Semiconductors**

For Semiconductors, the resistivity decreases as temperature increases since the value of α is negative.



(c) **For insulators**

The resistivity increases exponentially with decrease in temperature. It becomes infinitely large at temperatures near absolute zero.

11. It goes beyond doubt that electricity plays a very important role in our lives. It is one of the most important and convenient sources of energy at homes and industries. However, we daily come across reports regarding hazards of electricity. Use of electricity can prove to be very dangerous if certain precautions and safety measures are not observed in the design of electrical devices and in handling them. The various safety measures to be taken are:

(*i*) Use wires of high quality, proper amperage and good insulating material.
(*ii*) Cover all naked wires and joints with insulating tape.
(*iii*) All connections at plugs, switches, sockets must be tight.
(*iv*) Replace any defective plugs, switches and sockets.
(*v*) Never touch any part of the circuit without putting on rubber shoes or rubber gloves.
(*vi*) Use fuse (now a days MCB) of proper rating and material.
(*vii*) All electrical appliances must be properly earthed.
(*viii*) Connect switches and fuse to live wires.
(*ix*) Put out the main switch in case of short circuiting and fire.
(*x*) Do not use water as fire extinguishers in case of fire due to electricity.

12. Given, power of one heater (P) = 250 watt, potential (V) = 100 volt, time (t) = 5 hours.

(i) $P = \dfrac{V^2}{R}$; $R = \dfrac{V^2}{P} = \dfrac{100 \times 100}{250} = 40\ \Omega$

The three 250 watt heaters are connected in parallel then total current, $I = I_1 + I_2 + I_3$

$= \dfrac{V}{R_1} + \dfrac{V}{R_2} + \dfrac{V}{R_3} = \dfrac{100}{40} + \dfrac{100}{40} + \dfrac{100}{40}$

$= 2.5 + 2.5 + 2.5 = 7.5\ A$

(ii) The resistance of each heater is 40 Ω

(iii) The energy supplied to the first heater is $H = I^2Rt = (2.5)^2 \times 40 \times 5$ Wh, As current flowing each heater is 2.5 A

$\therefore$ $H = 6.25 \times 200$ Wh $= 1250$ Wh $= \dfrac{1250}{1000}$ kWh $= 1.25$ kWh

Then three heaters in connection = 3 × 1.25 kWh = 3.75 kWh energy is used in the circuit.

2 EXERCISE

Text-Book Question :

1. A combination of electrical devices connected by conducting wires is called an electric circuit.

2. Its S.I unit is ampere. If one coulomb of charge flows through a conductor in one second, then the amount of current flowing is said to be 1 ampere.

3. Charge on one electron = 1.6×10^{-19}C

$\therefore$ 1.6×10^{-19}C charge carried by 1 electron

$\therefore$ 1 C charge carried by

$= \dfrac{1}{1.6 \times 10^{-19}} = 6.25 \times 10^{18}$ electrons

4. Cell is the device that helps to maintain a potential difference across a conductor.

5. It means that 1 joule of work is done in carrying one coulomb charge between the two given points.

6. W = 6 × 1 = 6 joules

7. Resistance of a conductor depends upon

(i) nature of material (resistivity ρ)

(ii) length of wire (ℓ)

(iii) area of cross section of wire (A)

8. The current will flow through a thick wire easily because the resistance of the thick wire (having area of cross-section large as compared to thin wire) is less than thin wire.

9. At constant temp.

$V \propto I$ $\quad V_1 = V \quad I_1 = I$

$\dfrac{V_1}{V_2} = \dfrac{I_1}{I_2} \quad V_2 = \dfrac{V}{2} \quad I_2 = ?$

$\dfrac{V \times 2}{V} = \dfrac{I}{I_2} \quad \Rightarrow I_2 = \dfrac{I}{2}$

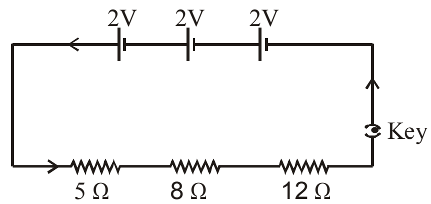
Current becomes half of its former value.

10. Alloys have high resistivity in comparison to pure metals. Also alloys do not oxidise readily at high temperatures but pure metals do. Therefore, alloys are used for making coils of electric toasters and electric irons rather than a pure metal.

11. (a) Iron is a better conductor than mercury because the resistivity of iron (=10 × 10^{-8} Ω m) is less than the resistivity of mercury (= 94 × 10^{-8} Ω m).

(b) Silver having least resistivity (= 1.6 × 10^{-8} Ω m) is the best conductor.

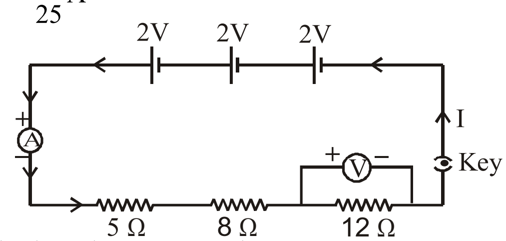
12.



13. V = iR

$V_{total} = 6V$, $R_{total} = 5 + 8 + 12 = 25\Omega$

$\therefore i = \dfrac{V}{R} = \dfrac{6}{25}$A



Reading in the voltmeter = V = iR

$= \dfrac{6A}{25} \times 12\Omega = 2.88V$

14. (i) $\dfrac{1}{R} = \dfrac{1}{1} + \dfrac{1}{10^6} = \dfrac{10^6 + 1}{10^6} = \dfrac{1000001}{1000000}$

$R = \dfrac{1000000}{1000001}\Omega$

(ii) $\dfrac{1}{R} = \dfrac{1}{1} + \dfrac{1}{10^3} + \dfrac{1}{10^6}$

$= \dfrac{10^6 + 10^3 + 1}{10^6} = \dfrac{1001001}{1000000}$

$R = \dfrac{1000000}{1001001} = 0.9\ \Omega$ (approx)

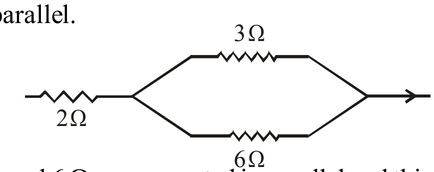
15. $\dfrac{1}{R} = \dfrac{1}{100} + \dfrac{1}{50} + \dfrac{1}{500} = \dfrac{5+10+1}{500} = \dfrac{16}{500}$

$R = \dfrac{500}{16} = 31.25\ \Omega$

$I = \dfrac{V}{R} = \dfrac{220}{31.25} = 7.04A$

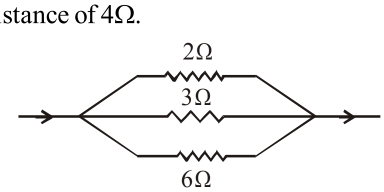
16. The equivalent resistance of resistors connected in parallel is less than even the smallest resistance connected in parallel, so, large current is obtained in the circuit for the same potential difference. So resistances are connecting in parallel.

17. (a)



3 Ω and 6 Ω are connected in parallel and this combination is connected in series to 2 Ω resistor to get an equivalent resistance of 4Ω.

(b)



All these three resistances are connected in parallel to get an equivalent resistance of 1 Ω.

18. (a) For highest resistance, resistors are connected in series.

$R_S = R_1 + R_2 + R_3 + R_4 = 4 + 8 + 12 + 24$
$= 48\Omega,$

(b) For lowest resistance, resistors are connected in parallel.

$$\frac{1}{R_p} = \frac{1}{4} + \frac{1}{8} + \frac{1}{12} + \frac{1}{24}$$

$$= \frac{6+3+2+1}{24} = \frac{12}{24} = \frac{1}{2} \quad \Rightarrow R_p = 2\,\Omega$$

19. According to the Joule's law of heating effect
$H = I^2RT$ and $H \propto R$
Because the resistance of heating element is very high. So more heat is developed, hence it glows. But the cord has very low resistance, so it does not glow.

20. $W = QV$
$\Rightarrow$ $H = QV = 96000 \times 50$ V
$H = 4800000$ J $= 4.8 \times 10^6$ J
$H = 4.8 \times 10^3$ kJ

21. $H = I^2 Rt = 5^2 \times 20 \times 30 = 15000$ J, H= 15 kJ

22. The rate at which energy is delivered by a current is called the power which is given by
$P = VI$
Thus, the potential difference (V) determine the power delivered by a current.

23. $I = 5A$; $V = 220V$
$P = VI = 220 \times 5 = 1100$ W
Energy consumed $= P \times t = 1100 \text{ W} \times 2 \text{ h} = 2200$ Wh $= 2.2$ kWh.

Text-Book Exercise :

1. (d) Now, resistance of each wire is R/5.

Equivalent resistance is given by $\frac{1}{R'}$

$$= \frac{5}{R} + \frac{5}{R} + \frac{5}{R} + \frac{5}{R} + \frac{5}{R} = \frac{25}{R}$$

$$\frac{R}{R'} = 25$$

2. (b)

3. (d) $P = \frac{V^2}{R} \Rightarrow R = \frac{V^2}{P} = \frac{220 \times 220}{100} = 484\,\Omega$

$$P = \frac{V^2}{R} = \frac{110 \times 110}{484} = 25W$$

4. (c) $R_S = R_1 + R_2 = R + R = 2R$

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{R} + \frac{1}{R} = \frac{2}{R}$$

$R_P = R/2$

$$\frac{H_1}{H_2} = \frac{V^2}{R_S}\frac{R_P}{V^2} = \frac{R_P}{R_S} = \frac{R}{2 \times 2R} = \frac{1}{4} = 1:4.$$

5. Voltmeter is connected in parallel to the appliance across which the potential difference is to be measured.

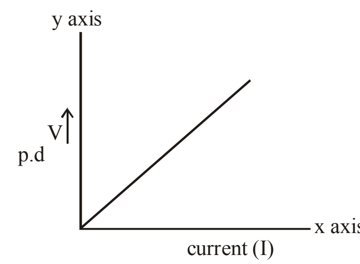
6. d $= 0.5$ mm $= 0.5 \times 10^{-3}$m
ρ $= 1.6 \times 10^{-8}$ Ωm
R $= 10\,\Omega$, ℓ = ?

$$R = \rho\frac{\ell}{A} \Rightarrow \ell = \frac{RA}{\rho}$$

$$\therefore \quad \ell = \frac{10 \times 22 \times 0.5 \times 0.5 \times 10^{-6}}{7 \times 4 \times 1.6 \times 10^{-8}} = 122.65 \text{ m}$$

If diameter is doubled, then resistance becomes one fourth.

7. Resistance from graph $= \frac{V_2 - V_1}{I_2 - I_1}$



$$R_1 = \frac{3.4-1.6}{1-0.5} = \frac{1.8}{0.5} = 3.6\,\Omega \;;$$

$$R_2 = \frac{6.7-3.4}{2.0-1.0} = 3.3\,\Omega$$

$$R_3 = \frac{10.2-6.7}{3-2} = 3.5\,\Omega \;;$$

$$R_4 = \frac{13.2-10.2}{4-3} = 3.0\,\Omega$$

Mean resistance,

$$R = \frac{R_1 + R_2 + R_3 + R_4}{4} = \frac{3.6+3.3+3.5+3}{4}$$

$$= \frac{13.4}{4}$$

$R = 3.35\,\Omega$

8. $V = 12V$; $I = 2.5$ mA $= 2.5 \times 10^{-3}$ A

$$R = \frac{V}{I} = \frac{12V}{2.5 \times 10^{-3}} = 4.8 \times 10^3\,\Omega$$

9. $R_S = 0.2 + 0.3 + 0.4 + 0.5 + 12\,\Omega = 13.4\,\Omega$

$$I = \frac{V}{R} = \frac{9V}{13.4\Omega} = 0.67A$$

10. $\frac{1}{R} = \frac{1}{176} + \frac{1}{176} + ---n \text{ times} = \frac{n}{176}$

$R = \frac{176}{n}$ and $I = \frac{V}{R} \Rightarrow 5 = \frac{220\,n}{176} \Rightarrow n = 4$

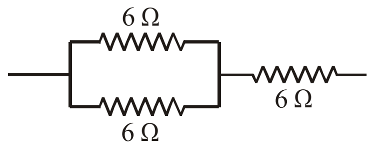
Number of resistors = 4.

11. (i) For getting a resistance of 9 Ω, the two resistors should be connected in parallel and one in series with them.

The equivalent resistance of the two resistors in parallel, R_p is given by

$$\frac{1}{R_p} = \frac{1}{6} + \frac{1}{6} = \frac{2}{6} \Rightarrow R_p = 3\,\Omega$$

Now, the equivalent resistance of R_p and 6 Ω in series is given by

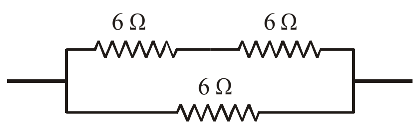


$$R = R_p + 6 = 3 + 6 = 9\,\Omega.$$

(ii) To get a resistance of 4 Ω, two resistors should be connected in series and one is parallel to them.
The equivalent resistance of the two resistors in series is given by

$$R_p = 6\,\Omega + 6\,\Omega = 12\,\Omega$$

Now, the equivalent resistance of R_p and 6 Ω in parallel is given by



$$\frac{1}{R} = \frac{1}{R_p} + \frac{1}{6} = \frac{1}{12} + \frac{1}{6} = \frac{1+2}{12} = \frac{3}{12} = \frac{1}{4}$$

$R = 4\Omega$

12. Resistance of each bulb = R (say)

$$R = \frac{V^2}{P} = \frac{220 \times 220}{10} = 4840\,\Omega$$

Let n such bulbs be connected in parallel. Then

$$\frac{1}{R_P} = \frac{1}{4840} + \frac{1}{4840} + \text{---} \text{n times} = \frac{n}{4840}$$

$$R_p = \frac{4840}{n}\Omega$$

$$R_p = \frac{V}{I} \quad \Rightarrow \quad I = \frac{V}{R_p}$$

$$5 \le \frac{220\,n}{4840}$$

$n \le 110$

Number of electric bulbs = 110.

13. Case (i) $I = \frac{V}{R} = \frac{220}{24} = 9.2\text{A}$

Case (ii) $R = 24 + 24 = 48\,\Omega$

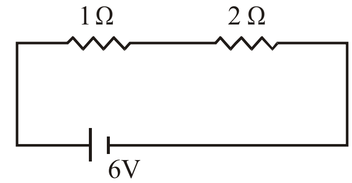
$$I = \frac{V}{R} = \frac{220}{48} = 4.6\text{A}.$$

Case (iii) $\frac{1}{R} = \frac{1}{24} + \frac{1}{24} = \frac{2}{24} = \frac{1}{12}$

$R = 12\,\Omega$

$$\therefore I = \frac{220}{12} = 18.3\text{ A.}$$

14. **Case (i)**

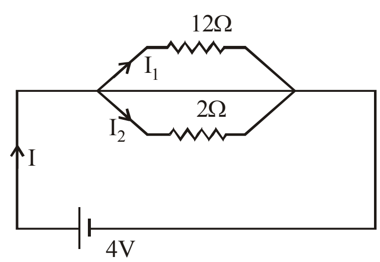


$R = 1 + 2 = 3\,\Omega$ and $I = \frac{V}{R} = \frac{6}{3} = 2\text{ A}$

∴ Voltage across 2Ω resistor = I × 2 = 2 × 2 = 4V

$P_1 = VI = 4 \times 2 = 8W$

Case (ii) $I_2 = \frac{V}{R_2} = \frac{4}{2} = 2\text{A}.$



P_2 across 2 Ω resistor = 4 × 2 = 8W

∴ ratio, $P_1 : P_2 = 8 : 8 = 1.$

15. Resistance of first lamp = R_1
Resistance of second lamp = R_2

$$R = \frac{V^2}{P}, \quad R_1 = \frac{220 \times 220}{100} = 484\,\Omega$$

$$R_2 = \frac{220 \times 220}{60} = \frac{2420}{3}\,\Omega$$

They are connected in parallel

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{484} + \frac{3}{2420}$$

$$R = \frac{484 \times 2420}{3\left(484 + \frac{2420}{3}\right)} = \frac{605}{2}\Omega$$

$$\therefore \quad I = \frac{V}{R} = \frac{220 \times 2}{605} = \frac{8}{11}\text{A}$$

$I = 0.727\text{A}$

16. $E = P \times t$

For T.V.	For toaster
$E_1 = 250 \times 1 \times 3600$	$E_2 = 1200 \times 10 \times 60$
$E_1 = 900000$ J	$E_2 = 720000$ J
$E_1 = 9 \times 10^5$ J	$E_2 = 7.2 \times 10^5$ J

$\Rightarrow E_1 > E_2$

∴ T.V. set uses more energy.

EBD_7005

17. $P = \frac{E}{t} = \frac{I^2Rt}{t} = I^2R = 15 \times 15 \times 8 = 1800$ W.

So, heat is developed at a rate of 1800 J/sec.

18. (a) Tungsten has very high melting point (3380°C). So it can't melt upto a high temperature. This is the reason why tungsten is used almost exclusively for filament of electric lamps.

(b) Resistivity of an alloy is generally higher than that of its constituent metals.

(c) In series arrangement, the potential drop is divided into different appliances. So, some appliances can not get sufficient potential drop for its proper working. This is possible only in parallel connection. Hence, series arrangement is not used for domestic circuits.

(d) The resistance of a wire is inversely proportional to its area of cross-section, i.e., $R \propto \frac{1}{A}$

(e) Copper and aluminium have low resistivity. Therefore, there will be less energy loss. Hence, they are usually empolyed for electricity transmission.

Exemplar Questi1ons :

1. If a current larger than a specified value flows in a circuit, temperature of fuse wire increases to its melting point. The fuse wire melts and the circuit breaks.

2. Use the formula $R = \rho\frac{1}{A}$. Also, V = RI. R is doubled while V remains unchanged. Hence current becomes $\frac{I}{2}$

3. Provide the same potential difference across each electrical appliance.

4. (i) No. The resistance of the bulbs in series will be three times the resistance of single bulb. Therefore, the current in the series combination will be one-third compared to current in each bulb in parallel combination. The parallel combination bulbs will glow more brightly.

(ii) In series circuit bulbs will not glow because the circuit has broken.

5. (i) $R = R_1R_2/(R_1+R_2) = \left(\frac{8\times8}{8+8}\right) = 4\Omega$

(ii) $I = V/R = 8/(4) + \left(\frac{8\times8}{8+8}\right) = 8/8 = 1A$

(iii) $V = IR = 1 \times 4 = 4V$

(iv) $P = I^2R = 1^2 \times 4 = 4W$

(v) No difference.

Same current flows through each element in a series circuit.

Hots Questions :

1. Maximum current through resistor

$A = \sqrt{\frac{18}{2}}A = 3A.$

Thus the maximum current through resistors B and C each

$3 \times \frac{1}{2}A = 1.5A$

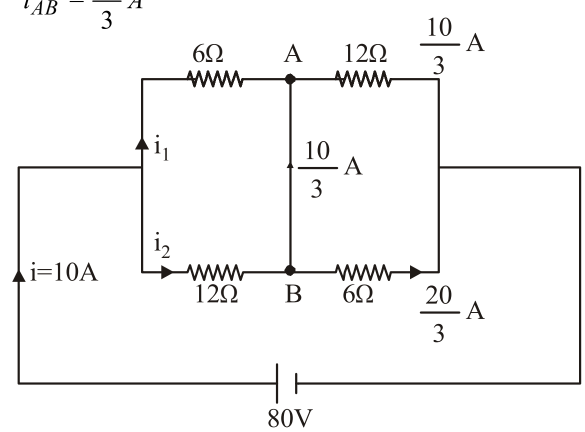
2. $R_{eq} = 8\Omega$

$i = \frac{80}{8} = 10A$

$i_1 = \frac{20}{3}A$

$i_2 = \frac{10}{3}A$

$i_{AB} = \frac{10}{3}A$



3. (a) $E = \frac{V}{L}$ and $R \propto \frac{L}{D^2}$

(i) When V is halved , E is halved, R = same

(ii) When L is halved , E = doubled, R is halved

(iii) When D is doubled , E = same R becomes $\frac{1}{4}$ th

4. Given : l = 10 cm, A = 2 cm^2, $R = 20\,\Omega$, P = ?

$R = P\frac{1}{A} \Rightarrow p = R.\frac{A}{l} = \frac{20x2}{10} = 4\,\Omega$-cm

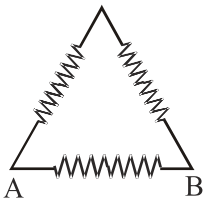
5. Manganin should be thicker, since resistivity is more (As $p \propto A$ for l and R constant).

3 EXERCISE

Single Option Correct :

1.	(a)	**2.**	(a)	**3.**	(c)	**4.**	(c)	**5.**	(d)
6.	(c)	**7.**	(c)	**8.**	(d)	**9.**	(c)	**10.**	(b)
11.	(d)	**12.**	(c)	**13.**	(b)	**14.**	(d)	**15.**	(b)
16.	(d)	**17.**	(b)	**18.**	(c)	**19.**	(c)	**20.**	(a)
21.	(c)	**22.**	(c)	**23.**	(d)	**24.**	(a)	**25.**	(c)
26.	(a)	**27.**	(b)	**28.**	(b)	**29.**	(c)	**30.**	(a)
31.	(b)	**32.**	(d)	**33.**	(c)	**34.**	(c)	**35.**	(b)
36.	(d)	**37.**	(a)	**38.**	(a)	**39.**	(a)	**40.**	(a)
41.	(b)	**42.**	(d)	**43.**	(b)	**44.**	(d)	**45.**	(b)
46.	(d)	**47.**	(b)	**48.**	(d)	**49.**	(c)	**50.**	(b)
51.	(b)	**52.**	(b)	**53.**	(b)				

54. (d) $R_{AB} = \dfrac{(4+4)\times 4}{4+4+4} = \dfrac{8}{3}\Omega$



55. (a) Same metal means same sp. resistance

$$\frac{R_1}{R_2} = \frac{A_2}{A_1} = \frac{1}{3} \quad \Rightarrow R_2 = 3R_1 = 3\times 10 = 30\Omega$$

$$R = R_1 + R_2 = 40\Omega$$

56. (c) $R \propto \dfrac{\ell}{A}$. Hence minimum for option (c)

57. (b) $R \propto \dfrac{1}{A} \propto \dfrac{1}{r^2}$. Hence $\dfrac{1}{4}^{\text{th}}$

58. (d) $R = \dfrac{\rho\ell}{A}$; $\ell = \dfrac{RA}{\rho} = \dfrac{4.2\times\pi\left(\dfrac{0.4}{2}\times 10^{-3}\right)^2}{4.8\times 10^{-8}} = 1.1m$

59. (c) Ideal voltmeter should not draw any current flow source hence its resistance $= \infty$.
Practically ∞ resistance is not possible, but ideal voltmeter is possible with the help of potentiometer that you will learn in higher classes.

60. (d) $R = \dfrac{\rho\ell}{A} = \dfrac{d\rho\ell^2}{m}$; $R \propto \dfrac{\ell^2}{m}$

$$\left[V = A\ell,\, d = \frac{m}{v} = \frac{m}{A\ell} \Rightarrow A = \frac{m}{d\ell}\right]$$

$$R_1 : R_2 : R_3 \equiv \frac{9}{1} : \frac{4}{2} : \frac{1}{3} \equiv 9 : 2 : \frac{1}{3} = 27 : 6 : 1$$

61. (c) Same material $\rightarrow$ same density, specific resistance as they are material property.

$$R = \frac{\rho\ell}{A} = \frac{\rho V}{A^2} = \frac{\rho m}{dA^2}$$

$$R \propto \frac{1}{A^2} \propto \frac{1}{r^4}$$

$$\frac{R_A}{R_B} = \frac{r_B^4}{r_A^4} = 2^4 = 16 \quad \Rightarrow \quad R_B = \frac{24}{16} = 1.5\,\Omega$$

62. (b) $R = \dfrac{\rho\ell}{A} = \dfrac{\rho\ell}{\pi r^2}$

$$R' = \frac{\rho 2\ell}{\pi(2r)^2} = \frac{R}{4}$$

Specific resistance will remain same as it is a material property but remember it depends on temperature.

63. (a) Two resistance ($R/2$) will be in parallel, hence $R_{eq} = R/4$

64. (a) $V = i \times R$; $R = 60/15 = 4\,\Omega$

65. (b)

66. (b) Silver is the best conductor of electricity.

67. (c)

68. (d) Copper is a conductor while germanium is a semi-conductor. Resistance of temperature decreases with temperature while that of semi-conductor increases hence resistance of copper strip decreases and that of germanium increases.

69. (d) 2Ω, 4Ω, 2Ω on right side are in series resultant parallel to 8Ω then in series with 2Ω, 2Ω then in parallel with 8Ω, then in series with 3Ω, 2Ω. Thus, $R_{eq} = 9$ ohm.
$i = 9/9 = 1$ amp flow from battery.
Passing through 3Ω it will divide into equal parts (1/2 amp) in 8Ω (near to cell) and remaining section then again divide into equal parts (1/4 amp) in 8Ω (middle one) and remaining section hence 1/4 amp. passes through 4Ω.

70. (a) **71.** (d) **72.** (d) **73.** (d) **74.** (c) **75.** (b)
76. (d) **77.** (c) **78.** (b) **79.** (a)

80. (d) Fuse wire should be such that it melts immediatley when strong current flows through the circuit. The same is possible if its melting point is low and resistivity is high.

81. (a) A heating wire should be such that it produces more heat when current is passed through it and also does not melt. It will be so if it has high specific resistance and high melting point.

82. (b) The rate of generation of heat, for a given potential difference is, $P = V^2/R$

83. (b) The rate of heat generation

$$= I^2 R = I^2 (\rho\ell/\pi r^2).$$

84. (a) Heat produced, $H = V^2 t/R$ i.e. $H \propto 1/R$
so $H_1/H_2 = R_2/R_1$..

More Than One Option Correct :

1. (a, d) **2.** (a, b, c) **3.** (c, d) **4.** (a, d)

5. (a, c, d) **6.** (a, d) **7.** (b, c)

8. (b, c) Treat all voltmeters and ammeters as resistances. Draw the circuit and find the currents and potential differences for each section.

9. (a, b, d) **10.** (a, d)

11. (a, c)
Let $R_1 + R_2$ be the resistances of the two heaters and H be the heat produced.

$$\therefore \quad H = \frac{V^2}{R_1}t_1 = \frac{V^2}{R_2}t_2$$

When used in series, $H = \dfrac{V^2 t}{R_1 + R_2}$

When used in parallel, $H = \left(\dfrac{V^2}{R_1} + \dfrac{V^2}{R_2}\right)t$

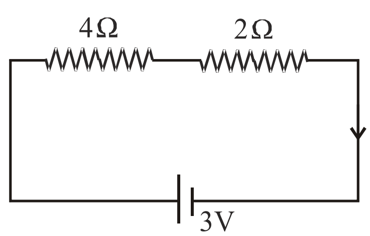
Passage Based Questions :

1. (a) Equivalent resistance of 3Ω and 6Ω = $\dfrac{3\times 6}{3+6} = 2\Omega$

as they are in parallel they have same p.d.

$$i = \frac{3}{6} = \frac{1}{2}$$

P.D. across $2\Omega = \dfrac{1}{2}\times 2 = 1$ volt



2. (b) **3.** (a)

4. (d) Given : $R_1 = 12\,\Omega,\ R_2 = 3.0\,\Omega,\ R_3 = 5.0\,\Omega,\ R_4 = 4.0\,\Omega,$
All four resistors are in series combination, so

$$R_s = R_1 + R_2 + R_3 + R_4$$

$$= 12\Omega + 3.0\Omega + 5.0\Omega + 4.0\Omega = 24\Omega$$

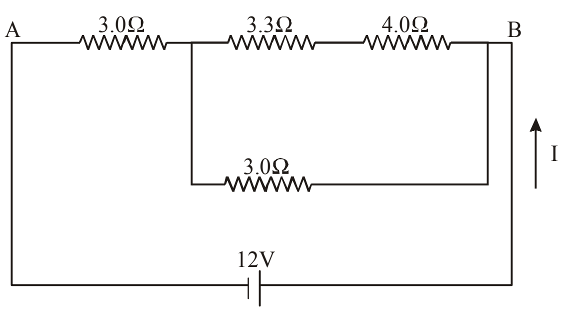
5. (c) The current through all resistors in series is the same

$$I = \frac{V}{R} = \frac{V}{R_s} = \frac{12V}{24\Omega} = 0.50\ A$$

6. (b) Potential drop across, 12Ω resistor
V = IR = 12Ω (0.5A)
or V = 6V

7. (b) Here we have a variety of series-parallel combinations. We follow the general procedures outlined in the text and above.
The 10 Ω and the 5.0 Ω are in parallel

$$R_{p_1} = \frac{(10\Omega)\,(5.0\Omega)}{10\Omega + 5.0\Omega} = 3.33\ \Omega$$



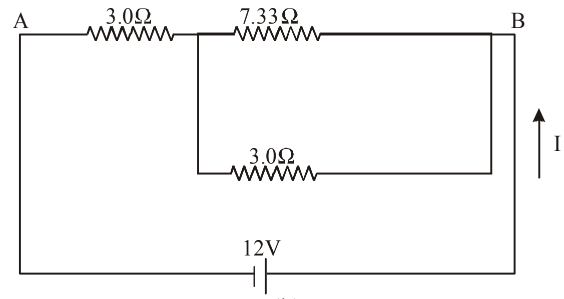
(a)

The circuit reduces to figure (a)

Now the 3.33 Ω and the 4.0 Ω are in series.

$$R_{s_1} = 3.33\Omega + 4.0\Omega = 7.33\ \Omega$$

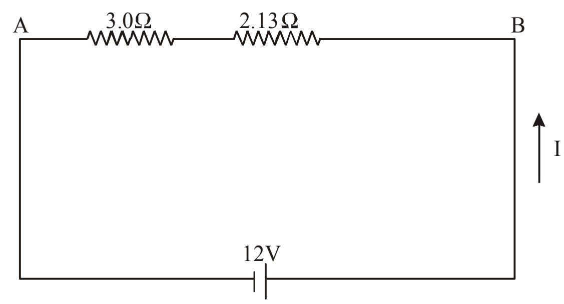
The circuit reduces to figure (b)



(b)

The 7.33 Ω and the 3.0 Ω are in parallel.

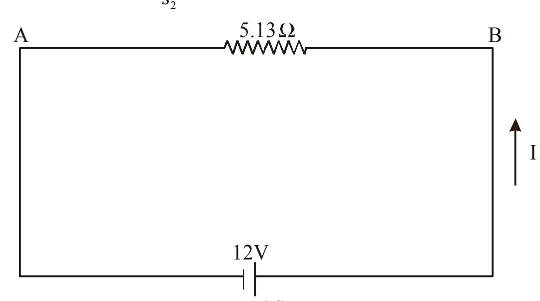
$$R_{p_2} = \frac{(7.33\Omega)\,(3.0\Omega)}{7.33\Omega + 3.0\Omega} = 2.13\Omega$$



(c)

The circuit reduces to figure (c).
Finally, the 2.13 Ω and the 3.0 Ω are in series.

$$R = R_{s_2} = 2.13\Omega + 3.0\Omega = 5.13\ \Omega = 5.1\Omega$$



(d)

The circuit reduces to figure (d).

8. (a) From Ohm's law, $I = \dfrac{V}{R} = \dfrac{12V}{5.13\Omega} = 2.33A = 2.3A$

9. (d) To find the current through the 4.0 ohm resistor, we need to expand the combinations.
In figure 3, the current through the 2.13 Ω and 3.0 Ω is the same as the total current, 2.33 A.
The voltage across the 2.13 Ω is then $V_{2.13} = (2.13\ \Omega)$ $(2.33\ \text{A}) = 4.96\ V$.
In figure 2, the voltage across the 7.33 Ω and 3.0 Ω is the same as that across the 2.13 Ω , 4.96V.

So, the current through the 7.33 Ω is

$$I_{7.33} = \frac{4.96V}{7.33\Omega} = 0.677A$$

In figure 1, the current through the 3.33 Ω and the 4.0 Ω is the same as the current through the 7.33 Ω

Therefore, $I_{4.0} = 0.68$ A.

10. (a) e.m.f. of the battery = $2V$

Effective resistance of the parallel resistors is given by R_1.

$$\frac{1}{R_1} = \frac{1}{6} + \frac{1}{2} = \frac{1+3}{6} = \frac{4}{6} = \frac{2}{3} \Rightarrow R_1 = \frac{3}{2} = 1.5\,\Omega$$

Total resistance of the circuit, $R = 1.5 + 0.5 = 2\Omega$

11. (a) Main current $I = \frac{V}{R} = \frac{2}{2} = 1A$

Current flowing through 0.5Ω resistor = $1A$

12. (d) P.D. across the junctions :

$V_1 = IR_1 = 1 \times 1.5 = 1.5V$

Hence current I_1, flowing through 6Ω resistor

$$I_1 = \frac{V_1}{6} = \frac{1.5}{6} = 0.25\ A$$

13. (a) When the lamps are connected in parallel, then potential difference V across each lamp will be same and will be equal to potential necessary for full brightness of each bulb. Because illumination produced by a lamp is proportional to electric power consumed in it, and power consumed,

$$P_1 = \frac{V^2}{R_1} < \frac{V^2}{R_2} = P_2$$

Hence, illumination produced by 2nd bulb will be higher than produced by lst bulb, i.e., bulb having lower resistance will shine more brightly.

14. (b) When R_1 burns out, then power is dissipated in R_2 only. Because internal resistance is quite low in lighting circuit, potential difference is still equal to V, hence, power dissipated in 2nd lamp, i.e.,

$$\frac{V^2}{R_2} < \left(\frac{V^2}{R_1} + \frac{V^2}{R_2}\right)$$

i.e., net power consumed initially. In other words, net illumination will now decrease.

15. (b) When two lamps are connected in series, the potential difference across each lamp will be different but current I flowing through each lamp will be same.

Hence, $P_1 = I^2R_1 > I^2R_2 = P_2$

i.e., illumination produced by lst lamp will be higher as compared to that produced by 2nd lamp, i.e., lamp having higher resistance will glow more brightly.

16. (b) When lamp of resistance R_2 burns out and only lamp of resistance R_1 is connected in the circuit then current flowing the circuit will change. Let new current be I'. Because potential difference still remains same (due to low internal resistance), hence

$I'R_1 = I(R_1 + R_2)$

or $I' = \frac{I(R_1 + R_2)}{R_1}$

If P' is the power consumed, then

$$P' = I'^2R_1 = I^2\frac{(R_1+R_2)(R_1+R_2)}{R_1}$$

When both the lamps were present then total power consumed was given by:

$P_S = P_1 + P_2 = I^2(R_1 + R_2)$, *i.e.,* $P' > P_S$

i.e., illumination gets increased when only one bulb is used.

17. (a) If a water pipe is given bend at some points, then it definitely reduces the flow of water in the pipe but this is not true in case of an electric current flowing in a conductor because electric current is established in a conductor due to drift motion of electrons in it along the line of the potential gradient. Hence, illumination is not affected due to bending along the length of supply wires.

Assertion & Reason :

1. (c) In the case of a short-circuited battery, the current

$$I = \frac{E\text{ (e.m.f. of the battery)}}{r\text{ (internal resistance)}} \neq 0$$

Terminal voltage $V = IR = I\,(i) = I\,(0) = 0$

where R = external resistance = 0

2. (c) It is common error to say that V = Ri is a statement of Ohm's law. The essence of Ohm's law is that the value of R is independent of the value of V. The equation $V = Ri$ is used for finding resistance of all conducting devices, whether they obey Ohm's law or not.

3. (c) (a) will read zero but (V) will read E

4. (c) ρ is the characteristic of the material of resistors. It does not depend on the length and cross-sectional area of resistors. But R depends on the length and the cross-sectional are of the resistor.

So, R_1 may be greater than R_2 even when $\rho_1 \le \rho_2$.

5. (c) $\text{Conductivity} = \frac{1}{\text{Resistivity}}$

$\therefore$ conductivity × resistivity = 1

6. (a)

7. (d) S.I. is true only when current is drawn from cell.

8. (c) Resistivity is a material property.

9. (c) $\rho = \rho_0(1 + \alpha\,\Delta T)$

10. (b) Glow = Power $(P) = I^2R$

$$\therefore \frac{dP}{P} = 2\left(\frac{dI}{I}\right) = 2 \times 0.5 = 1\%$$

11. (b) Power loss = $i^2R = \left(\frac{P}{V}\right)^2 R$

[P = Transmitted power]

12. (b) $P=\dfrac{V^2}{R}$; $R\propto\dfrac{1}{P}$ (same rated voltage)

13. (d) In tube light majority portion of radiation comes under visible region while bulb radiation consists of visible, ultraviolet, infrared radiation giving less visible part.

14. (c) Here, $P=\dfrac{E^2}{R}$, so $P \propto R$ only when I is constant.

Here I increases as R is decreased. Hence the reason is wrong.

15. (a)

16. (c)

Multiple Matching Questions :

1. (a) (A) → q, s; (B) → p; (C) → q, s; (D) → r

2. (a) (A) → p; (B) → p; (C) → s, q; (D) → r

3. (b) (A) → p; (B) → q, r; (C) → q; (D) → s

4. (a) (A) → q ; (B) → r; (C) → p,s (D) → s

Integer/ Numeric Questions :

4. Total power = 100 + 25 = 125 W
Power = V × I

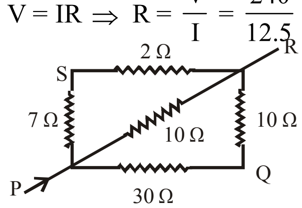
$$I=\frac{P}{V}=\frac{125}{220}=0.57\text{ A}$$

5. P = 3000 W, V = 240 V

$$P=VI \Rightarrow I=\frac{P}{V}=\frac{3000}{240}=12.5\text{ A}$$

$$V=IR \Rightarrow R=\frac{V}{I}=\frac{240}{12.5}=19.2\ \Omega$$

6.



$R_1=7\ \Omega$, $R_2=2\ \Omega$, $R_3=10\ \Omega$,

$R_4=30\ \Omega$, $R_5=10\ \Omega$, $V=6$ V

Now, R_1 and R_2 are in series,

$R'=R_1+R_2=7+2=9\ \Omega$

Also, R_4 and R_5 are in series,

$R''=R_4+R_5=30+10=40\ \Omega$

Now, R', R'' and R_3 are in parallel,

$$\frac{1}{R}=\frac{1}{R'}+\frac{1}{R''}+\frac{1}{R_3}$$

$$\Rightarrow \frac{1}{R}=\frac{1}{9}+\frac{1}{40}+\frac{1}{10}$$

$$\Rightarrow \frac{1}{R}=\frac{40+9+36}{360}=\frac{85}{360}$$

$$\therefore R=\frac{360}{85}=4.23\ \Omega$$

$$V=IR \Rightarrow I=\frac{V}{R}=\frac{6}{4.23}=1.41\text{ A}$$

7. $R_1=7.2\ \Omega$, $R_2=8\ \Omega$, $R_3=12\ \Omega$, $V=6$ V

(i) Now, R_1 and R_3 are in parallel,

$$\frac{1}{R'}=\frac{1}{R_2}+\frac{1}{R_3}=\frac{1}{8}+\frac{1}{12}$$

$$=\frac{3+2}{24}=\frac{5}{24}\Rightarrow R'=\frac{24}{5}=4.8\ \Omega$$

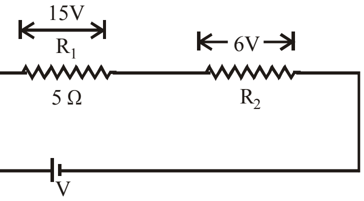
Now, R_1 and R' in series,

$R=R_1+R'=7.2+4.8=12\ \Omega$

(ii) $V=IR \Rightarrow I=\dfrac{V}{R}=\dfrac{6}{12}=0.5$ A

(iii) $V_1=I\times R_1=0.5\times 7.2=3.6$ V.

8. (i)



$R_1=5\ \Omega$, $V_1=15$V, $R_2=?$, $V_2=6$ V

$$I=\frac{V_1}{R_1}=\frac{15}{5}=3\text{ A}$$

(ii) $I=\dfrac{V_2}{R_2}\Rightarrow R_2=\dfrac{V_2}{I}=\dfrac{6}{3}=2\ \Omega$

$V=V_1+V_2\Rightarrow V=15+6=21$ V.

9. V = 250 V, t = 10 sec, R = 500 Ω,
E = ?, I = ?, V = IR

$$I=\frac{V}{R}=\frac{250}{500}=0.5\text{ A}$$

$E=I^2Rt=0.5\times0.5\times500\times10=1250$ J.

10. P = 2000W, t = 1 hr. E = ?

$$E=n\times P\times t=1\times\frac{2000}{1000}\times1=2\text{ kWh.}$$

T.E. = 30 × 2 = 60 kWh.

11. $R_1=5\ \Omega$, $R_2=10\ \Omega$, $R_3=15\ \Omega$, $I=1$ A

(i) $\dfrac{1}{R'}=\dfrac{1}{R_2}+\dfrac{1}{R_3}=\dfrac{1}{10}+\dfrac{1}{15}=\dfrac{3+2}{30}=\dfrac{5}{30}$

$$R'=\frac{30}{5}=6\ \Omega$$

$R=R_1+R'=5+6=11\ \Omega$

Now, $V = IR = 1 \times 11 = 11V$

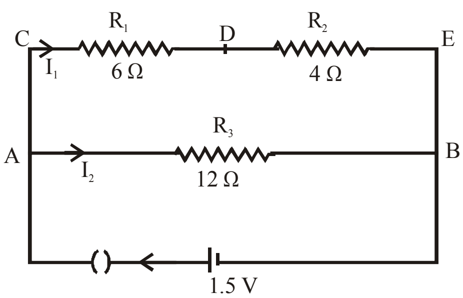
(ii) $V_1 = I R_1 = 1 \times 5 = 5$ V.

Therefore, $V_2 = V - V_1 = 11 - 5 = 6V$

(iii) $V_2 = I_1 R_2 \Rightarrow I_1 = \frac{V_2}{R_2} = \frac{6}{10} = 0.6\,A;\ I_2 = \frac{V_2}{R_3}$

$= \frac{6}{15} = 0.4\,A$

12.



R_1 and R_2 are in series

$\therefore\ R_S = R_1 + R_2 = 6 + 4$

$R_S = 10\,\Omega$

R_S and R_3 are in parallel

$$\therefore \frac{1}{R_P} = \frac{1}{R_S} + \frac{1}{R_3} = \frac{1}{10} + \frac{1}{12}$$

$$\frac{1}{R_P} = \frac{6+5}{60} = \frac{11}{60}$$

$$R_P = \frac{60}{11}\Omega$$

$$I = \frac{V}{R_p} = \frac{1.5 \times 11}{60} = \frac{11}{40}A$$

$$I_2 = \frac{V}{R_3} = \frac{1.5}{12} = \frac{3}{40} = 0.075A$$

$$I_1 = \frac{1.5}{R_S} = \frac{1.5}{10} = 0.15A.$$

$$V_{AB} = I_2 R_3 = \frac{3}{40} \times 12 = 0.9V$$

$V_{CD} = I_1 R_1 = .15 \times 6 = 0.9V$

$V_{DE} = I_1 R_2 = 0.15 \times 4 = 0.6V$

13. $d = 0.5$ mm $\Rightarrow 0.5$ mm $= \frac{1}{1000} \times 0.5$ m

(Since 1000 mm = 1m)

$d = 5 \times 10^{-4}$ m.

$$r = \frac{d}{2} = \frac{5 \times 10^{-4}}{2} = 2.5 \times 10^{-4}\ \text{m}$$

$R = 10\,\Omega$, $\rho = 16.2\,\Omega$ m, $L = ?$

$$R = \rho\frac{L}{A}$$

$$L = \frac{R \times A}{\rho} = \frac{10 \times \pi r^2}{\rho}$$

$$= \frac{10 \times 22 \times 25 \times 25 \times 10^{-8}}{7 \times 16.2 \times 10 \times 10} = 121.25 \times 10^{-9}\ \text{m}$$

$= 12.12 \times 10^{-8}$ m.

14. $L = 60$ cm $= 0.6$ m, $\rho = 2.6 \times 10^{-8}\ \Omega$ m, $R = ?$,
$A = 1\text{mm}^2$

$$1\ \text{mm}^2 = \frac{1}{10^6} = 10^{-6}\text{m}^2$$

Therefore, $R = \rho\frac{L}{A}$

$$R = \frac{2.6 \times 10^{-8} \times 0.6}{10^{-6}} = 1.56 \times 10^{-2}\ \Omega$$

15. Given : $1 = 0.2\ A$, $V = 0.8\ V$, $R = ?$
From Ohm's law, $V = IR$

$$\therefore R = \frac{V}{1} = \frac{0.8}{0.2} = 4\,\Omega$$

16. 12Ω and 4Ω since in parallel they give 3Ω and in series they give 16Ω

17. The resistance of bulb and heater we respectively 240Ω and $60\,\Omega$, and these are connected in parallel. Their equivalent resistance is $48\,\Omega$. When only bulb is switched on, current from the mains is

$\frac{120V}{(240+6)\,\Omega} = 0.488$ A. When heater is also turned on, current becomes $\frac{120V}{(48+6)\,\Omega} = 2.22$ A

18. Resistance of 60 W bulb is more than in 100 W bulb. So equivalent resistance of the network drops on placing 100 W bulb and so the power or heat $\left(\frac{V^2}{R}t\right)$ is more

19. Since, $P = \frac{V^2}{R}$, $P_1 : P_2 = R_2 : R_1 = 2 : 1$

20. Electrical energy consumed in 30 days
$= 500 \times 2 \times 30 + 0.5 \times 746 \times 5 \times 30$ (1 hp = 746 W)
$= 30000 + 55950 = 85950$ Wh $= 85.95$kW h
Cost of energy $= 3 \times 85.95 =$ ₹ 258.

21. (i) $R = \frac{V^2}{P} = \frac{220^2}{100} = 484\Omega$

(ii) Energy consumed per day
$= P \times t = 100 \times 5 = 500$ Wh $= 0.5$ k Wh.

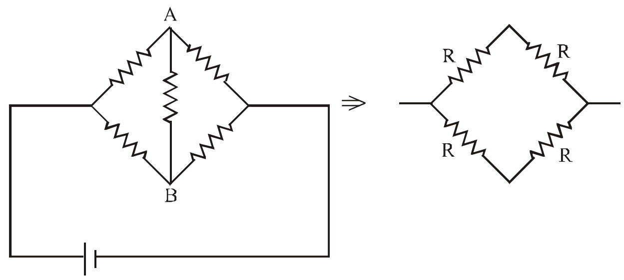
22. Power of lamp = 60 W
Light liberated = 7.5 W

% of transfer $= \frac{7.5}{60}$ x 100 = 12.5%

4 ADVANCED EXERCISE
BASED ON CONNECTING TOPICS

1. (c) $i \propto$ division deflected.
$V = 50G$, $50G = 10\,(G + 12)$; $G = 3\Omega$

2. (b)



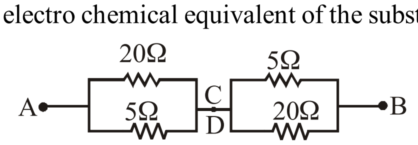
As Wheatstone bridge is in balanced condition potential difference across AB is zero hence resistance across AB is ineffective circuit reduce to simple circuit as shown resistance R in upper branch are in series and in parallel with lower branch.
$R_{eq} = R$.

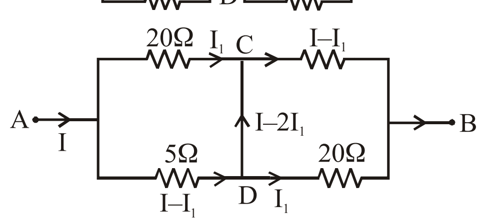
3. (a) **4.** (b) **5.** (b) **6.** (b) **7.** (d) **8.** (b)
9. (b) **10.** (c) **11.** (d) **12.** (a)
13. (a) In parallel combination, total power $P = P_1 + P_2$
14. (d)
15. (c) $m_{Ag}/m_{Zn} = E_{Ag}/E_{Zn} = 108/31$

or $m_{Ag} = m_{Zn} \times 108/31 = W \times 108/31$

16. (d)
17. (a) Faraday's laws are based on the conversion of electrical energy into mechanical energy; which is in accordance with the law of conservation of energy.
18. (b) The amount of decomposition (i.e., mass of the substance liberated during electrolysis) is proportional to electro chemical equivalent of the substance.

19. (a,b,d)





As C and D are joined, they must be at the same potential, and may be treated as the same point. This gives the equivalent resistance as 8Ω. If we distribute current in the network, using symmetry

$V_A - V_D = V_A - V_C$

or $20I_1 = 5\,(I - I_1)$ or $I_1 = \dfrac{I}{5}$

$\therefore \quad I - 2I_1 = 1 - \dfrac{2I}{5} = \dfrac{3I}{5}$

= Current flowing from D to C

20. (a,b)
The effective *emf* the two cells in parallel is

$$e = \frac{1\times 2 - 2\times 1}{1+2} = 0.$$

So null point will be at zero distance from A. When jockey is touched to B, the current flows through 2 V cell towards B.

21. (a, b, c)
Let $E_1 < E_2$.

Current in the circuit $= I = \dfrac{E_1 - E_2}{r_1 + r_2}$

$V_A - V_B = E_2 + Ir_2 = PD$ across each cell
Hence, $V_A - V_B > E_2$
Current flows in E_2 from the positive plate to the negative plate inside the cell and hence it absorbs energy.

22. (a, d)
Equivalent e.m.f. of the battery is obtained by applying Kirchhoff's 2nd law to the two loops.

$$E_3 = \frac{E_1R_2 + E_2R_1}{R_1 + R_2}$$

23. (a, c, d)
24. (a, c)
4Ω and 6Ω resistances are short circuited. Therefore, no current will flow through these two resistances. Current passing through the battery is $I = (20/2) = 10A$.
This is also the current passing in wire AB from B to A.
Power supplied by the battery.
$P = EI = (20)\,(10) = 200$ Watt
Potential difference across 4Ω resistance
= Potential difference across 6Ω resistance = 0

25. (a) Potential gradient,

$$K = \frac{V_{AB}}{L} = \frac{I\times R}{L} = \frac{4 \text{ volt}}{(15+10)\text{ ohm}} \times \frac{10 \text{ ohm}}{50 \text{ cm}}$$

$$= \frac{40}{25\times 50}\text{Volt/cm}$$

$$\therefore \; E_2 = Kl = \frac{40}{25\times 50}\times 31.25 = 1\text{volt}$$

26. (d) When both the keys are closed: In the situation, R_1 is short circuited and terminal potential difference of E_2 is balanced by the potentiometer, i.e.,

$$\frac{E_2}{R_2 + r}\times R_2 = Kl = \frac{4\times 10}{10\times 50}\times 5$$

$$\frac{1\times 5}{5+r} = \frac{4}{50}\times 5 \text{ or } r = 7.5\Omega$$

27. (c) When key K_2 is open and K_1 is closed: In this case R_1 is short circuited and e.m.f. E_2 is balanced against potentiometer,

i.e., $E_2 = \left[\dfrac{4}{10}\times\dfrac{10}{50}\right]\times l = \dfrac{1\times 10\times 50}{4\times 10} = 12.5$ cm

28. (c) When key K_1 is open and K_2 is closed: In this case, R_1 is included in the potentiometer circuit and terminal potential difference of E_2 is balanced by the potentiometer.

i.e., $\dfrac{E_2 R_2}{R_2 + r} = \left[\dfrac{4}{25} \times \dfrac{10}{50}\right] \times l$

or $\dfrac{1 \times 5}{5 + 7.5} = \dfrac{4}{1.25} \times l$

or $l = 12.5$ cm

29. (c) Kirchoff's loop rule follows from conservation of energy.

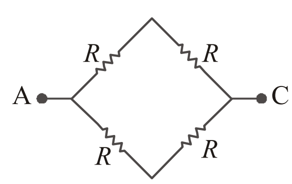
30. (d) In tube light majority portion of radiation comes under visible region while bulb radiation consists of visible, ultraviolet, infrared radiation giving less visible part.

31. (c) Here, $P = \dfrac{E^2}{R}$, so $P \propto R$ only when I is constant.

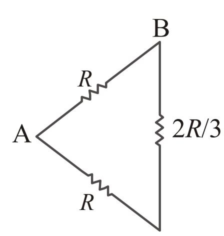
Here I increases as R is decreased. Hence the reason is wrong.

32. (a)

A-r : $R_{AC} = R$



B-q : $R_{AB} = \dfrac{5R}{8}$



C-p : It is the balance bridge and so $V_B = V_D$.

D-t : $V_B \neq V_D$.

33. Using kirchhoff's II law in loop abcda

$-2I_1 + 24 - 27 - 6I_2 = 0$

or $2I_1 + 6I_2 = -3$ ......(1)

Using kirchhoff's II law in loop cdfec we get

$-27 - 6I_2 + 4I_3 = 0$

or $-6I_2 + 4I_3 = 27$ ......(2)

From junction rule at c we get

$I_1 = I_2 + I_3$ ......(3)

From 2 and 3 we get

$-6I_2 + 4(I_1 - I_2) = 27$

or $4I_1 - 10I_2 = 27$ ......(4)

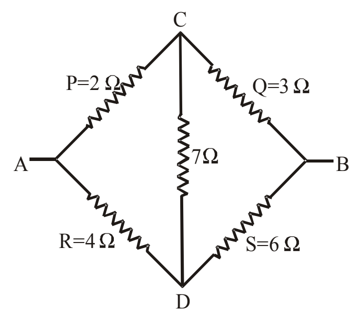
Solving eq^{n}s (1) and (4) we get

$I_1 = 3$A, $I_2 = -1.5$ A so $I_3 = I_1 - I_2 = 4.5$ A

Negative I_2 means the direction should have been opposite to shown in figure.

34. The circuit can be redrawn as

Here $\dfrac{P}{Q} = \dfrac{R}{S} = \dfrac{2}{3}$ so bridge is balanced



So the resistance between c and d is non useful.

Equivalent resistance = (P + Q) | | (R + S)

$$R_{eq} = \frac{(P+Q)(R+S)}{P+Q+R+S} = \frac{(2+3)(4+6)}{2+3+4+6}$$

$$= \frac{5 \times 10}{15} = \frac{10}{3}\Omega$$

35. $\dfrac{P}{Q} = \dfrac{L}{100 - L} = \dfrac{2}{3}$

so, $3L = 200 - 2L$ or $L = \dfrac{200}{5} = 40$ cm.

36. Since, $P = \dfrac{V^2}{R}$, $P_1 : P_2 = R_2 : R_1 = 2 : 1$

37. Resistance of heater coil

$$\frac{V^2}{P} = \frac{200^2}{100} = 400\Omega$$

Resistance of each cut part = 200Ω

When connected in parallel, the net resistance will be 100Ω

Energy liberated per second

$$= \frac{V^2}{R} = \frac{200^2}{100} = 400\ \Omega \text{ joule}$$

Chapter 4

MAGNETIC EFFECTS OF ELECTRIC CURRENT

INTRODUCTION

The term magnetism comes from Magnesia, the name of an ancient city in Asia Minor, where the Greeks found certain very unusual stones more than 2000 years ago. These stones, called lodestones, possess the unusual property of attracting pieces of iron. Such magnets were first fashioned into compasses and used navigation by the Chinese in the twelfth century A.D.

In the sixteenth century, William Gilbert, Queen Elizabeth's physician, made artificial magnets by rubbing pieces of iron against lodestones. He suggested that a compass always points north and south because the earth itself shows the magnetic properties. Later in 1750, John Michaell in England found that magnetic poles obey the inverse-square law, and his results were confirmed by Charles Coulomb. The subjects of magnetism and electricity developed almost independently until 1820, when a Danish physicist named Hans Christian Oersted discovered, in a classroom demonstration, that an electric current affects a magnetic compass. He saw that magnetism was related to electricity. Shortly thereafter, the French physicist Andre Marie Ampere proposed that electric currents are the source of all magnetic phenomena. This chapter is all about how electricity is connected with magnetism. The branch of physics which deals with the magnetism produced due to electric current is called **electromagnetism.**

OERSTED EXPERIMENT

Magnetic effect of electric current means-an electric current flowing in a conductor produces a magnetic field in the space around it. In 1820, **Hans Christian Oersted** Showed that electricity and magnetism are related phenomena.

Oersted discovered a magnetic field around a conductor carrying electric current.

(a) A magnet at rest produces a magnetic field around it while an electric charge at rest produces an electric field around it.

(b) A current carrying conductor has a magnetic field and not an electric field around it. On the other hand, a charge moving with a uniform velocity has an electric as well as a magnetic field around it.

(c) An electric field cannot be produced without a charge whereas a magnetic field can be produced without a magnet.

(d) No poles are produced in a coil carrying current but such a coil shows north and south polarities.

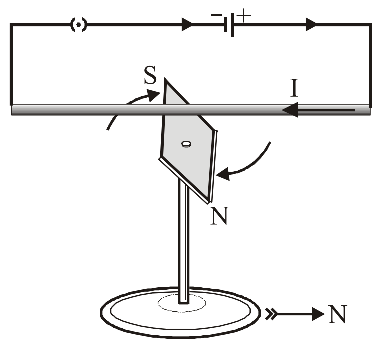
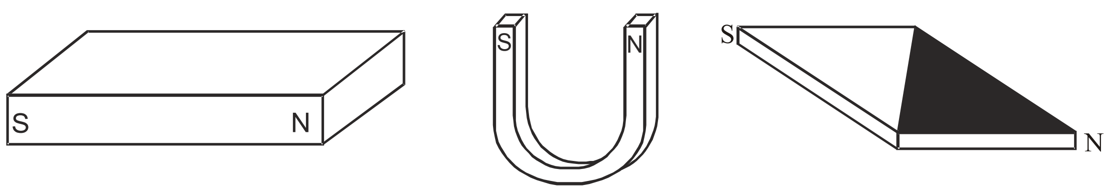


Fig.4.1

(e) All oscillating or an accelerated charge produces E.M. waves also in addition to electric and magnetic fields.

ARTIFICIAL MAGNETS

Magnets produced from magnetic materials are called artificial magnets. They can be made in a variety of shapes and sizes and are used extensively in electrical apparatus.



(a) Bar magnet (b) U-shape or horseshoe magnet (c) Magnetic-needle

Fig. 4.2

Artificial magnets are generally made from special iron or steel alloys which are usually magnetized electrically. The material to be magnetized is inserted into a coil of insulated wire and a heavy flow of electrons is passed through the wire. Magnets can also be produced by stroking a magnetic material with magnetite or with another artificial magnet. The forces causing magnetization are represented by magnetic lines of force.

Artificial magnets are usually classified as permanent or temporary, depending on their ability to retain their magnetic properties after the magnetizing force has been removed. Magnets made from substances, such as hardened steel and certain alloys which retain a great deal of their magnetism, are called permanent magnets. These materials are relatively difficult to magnetize because of the opposition offered to the magnetic lines of force as the lines of force try to distribute themselves throughout the material. The opposition that a material offers to the magnetic lines of force is called **reluctance**. All permanent magnets are produced from materials having a high reluctance.

A material with a low reluctance, such as soft iron or annealed silicon steel, is relatively easy to magnetize but will retain only a small part of its magnetism once the magnetizing force is removed. Materials of this type that easily lose most of their magnetic strength are called temporary magnets. The amount of magnetism which remains in a temporary magnet is referred to as its residual magnetism. The ability of a material to retain an amount of residual magnetism is called the **retentivity** of the material.

Magnets are also described in terms of the **permeability** of their materials, or the ease with which magnetic lines of force distribute themselves throughout the material. A permanent magnet, which is produced from a material with a high reluctance, has a low permeability. A temporary magnet, produced from a material with a low reluctance, would have a high permeability.

PROPERTIES OF MAGNETS

(1) **Attractive property and poles :** When a magnet is dipped into iron fillings it is found that the concentration of iron filings, i.e., attracting power of the magnet is maximum at two points near the ends and minimum at the centre. The places in a magnet where its attracting power is maximum are called poles while the place of minimum attracting power is called the neutral region.

(2) **Directive property and N-S poles :** When magnet is suspended its length becomes parallel to N-S direction. The pole pointing north is called the north (N) pole while the other pointing south is called the south (S) pole.

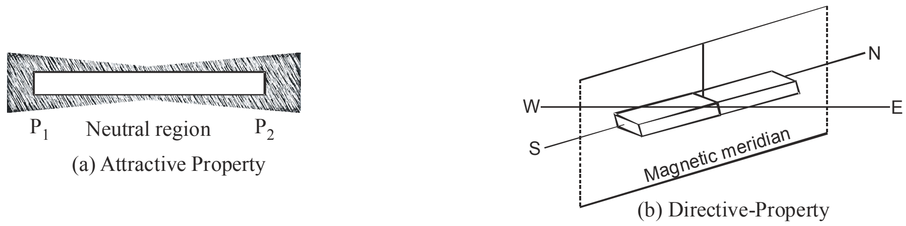


Fig. 4.3

(3) Opposite poles (N and S) attract and like poles (N and N, or S and S) repel one another.

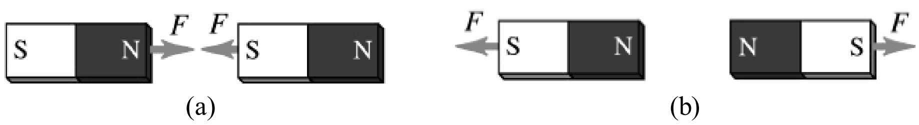


Fig. 4.4

The line joining the two poles of a magnet is called **magnetic axis** and the vertical plane passing through the axis of a freely suspended or pivoted magnet is called **magnetic meridian**.

Magnetic Length (2ℓ) : The distance between two poles along the axis of a magnet is called its effective or magnetic length. As poles are not exactly at the ends, the effective length is lesser than the actual length of the magnet.

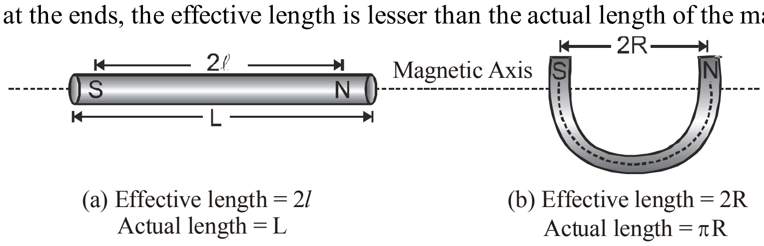


Fig. 4.5

(4) **Poles exist in pairs :** In a magnet the two poles are found to be equal in strength and opposite in nature. If a magnet is broken into number of pieces, each piece becomes a magnet with two equal and opposite poles. This shows that monopoles do not exist.

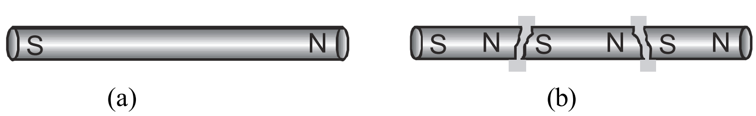


Fig. 4.6

(5) **Repulsion is a sure test of polarity :** A pole of a magnet attracts the opposite pole while repels similar pole. A sure test of polarity is repulsion and not attraction, as attraction can take place between opposite poles or a pole and a piece of unmagnetised magnetic material due to 'induction effect'.

(6) **Magnetic induction :** A magnet attracts certain other substances through the phenomenon of magnetic induction i.e., by inducing opposite pole in a magnetic material on the side facing it as shown in fig.

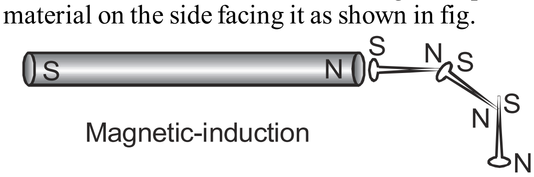


Fig. 4.7

Interesting Fact

Seeds of two tomatoes varieties Rocco and Monza were treated by passing them through an artificial magnetic field (MF) with a constant defined velocity before seeding. The seedlings obtained from MF treated and non MF-treated seeds were planted into the MF treated and non MF-treated plots. They were irrigated by MF-treated and non MF treated water.

Observations were made on early-yield, total-yield, beginning of blooming, and quality of fruit. While significant differences were not observed in Rocco, important MF effects were clearly seen on Monza. Yield increases on Monza in magnet treated plots were around 28–51 percent, especially in early yields, and Monza bloomed three-four days earlier.

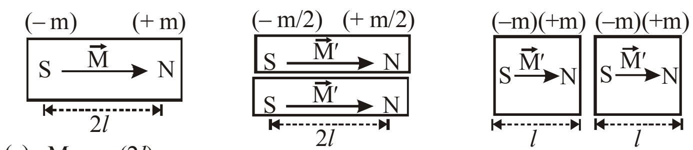
CONNECTING TOPIC

POLE STRENGTH AND MAGNETIC MOMENT OF A MAGNET

The strength of attracting a magnetic material by a magnetic pole is measured by pole strength, generally denoted by *m*.

The north and south poles of a magnet are said to be associated with the pole strengths $+m$ and $-m$, respectively, each of which is a scalar, having the **dimensional formula** $[M^oLT^oA]$ and **SI unit** Am.

Each pole strength is imagined to be distributed over the entire cross-section of the magnet. Therefore, if the magnet is cut along it's length into the two equal parts, each part will have it's poles of the strengths $+m/2$ and $-m/2$, respectively, and if the magnet is cut perpendicular to it's length into the two equal parts, each part will have it's poles of same initial strengths $+m$ and $-m$, respectively.



(a) $M = m(2l)$ (b) $M' = (m/2)(2l) = ml = M/2$ (c) $M' = m(l) = M/2$

Fig. 4.8

The **magnetic moment** of a magnet is defined as a vector $\vec{M}$ whose magnitude is $M = n(2l)$

where m is the pole strength of magnet and $2l$ is the effective length of magnet and whose direction is from the south pole to the north pole. It has the **dimensional formula** $[M^oL^2T^oA]$ and **SI unit** Am^2.

If the magnet is cut along it's length, or perpendicular to its length, into the two equal parts, each part will have it's magnetic moment of magnitude one-half of that of the original magnetic moment, as shown above.

COULOMB'S LAW IN MAGNETISM

This law defines the force F between the two magnetic poles of the strengths m_1, m_2 at a distance r apart in a medium as

$$F = \left(\frac{\mu}{4\pi}\right)\left(\frac{m_1 m_2}{r^2}\right) \text{ (in SI unit)} \qquad F = \left(\frac{1}{\mu}\right)\left(\frac{m_1 m_2}{r^2}\right) \text{ (in CGS unit)}$$

where μ is the permeability of medium and $\mu = \mu_0 = 4\pi \times 10^{-7}\ N/A^2$ in SI and $\mu = \mu_0 = 1$ (unitless) in CGS. Evidently, the force F is directly proportional to the product of the pole strengths and inversely proportional to the square of the distance r. It acts along the line joining the two magnetic poles. It is attractive for the unlike magnetic poles and repulsive for the like magnetic poles. It depends on the medium in which the magnetic poles are situated.

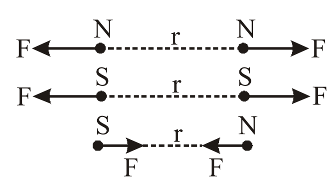


Fig. 4.9

CHECK Point

A friend tells you that a refrigerator door, beneath its layer of white-painted plastic, is made of aluminum. How could you check to see if this is true (without any scraping) ?

SOLUTION

I will bring a magnet and make it touch with the refrigerator door. If the magnet shows a feeble attraction with it then I can say that it is aluminum.

ILLUSTRATION : 4.1

Four identical bar magnets, each of magnetic moment *M*, are arranged to form a square, as shown. Calculate the resultant magnetic moment of the system.

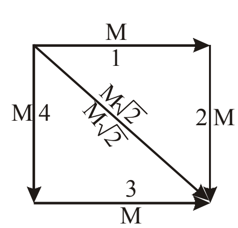


Fig. 4.10

SOLUTION :

The magnetic moments of the given four identical bar magnets are acting along the sides of a square, as shown. The resultant of each of the two pairs of magnetic moments, *i.e.*, (1, 4) and (2, 3), is $M\sqrt{2}$ and it is represented by the same diagonal of the square.

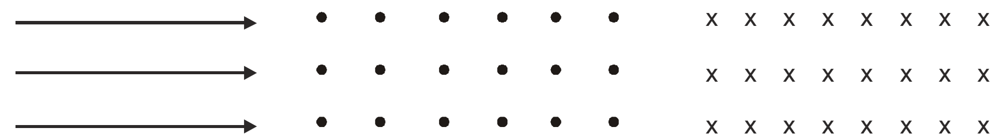
Therefore, the resultant of all the four magnetic moments, taken together, is $2\sqrt{2}M$, which is acting along the diagonal.

MAGNETIC FIELD AND MAGNETIC FIELD LINES

Magnetic Field

The space around a magnet (or a current carrying conductor) in which its magnetic effect can be experienced is called the magnetic field. It is a quantity that has both direction and magnitude.

The magnetic field in a region is said to be uniform if the magnitude of its strength and direction is same at all points in that region.



(a) Uniform field in plane of paper

(b) Uniform field perpendicular to plane of paper outwards

(c) Uniform field perpendicular to plane of paper inwards

Fig. 4.11

The strength of magnetic field is also known as magnetic induction or magnetic flux density.

The **SI unit** of strength of magnetic field is tesla (T)

1 tesla = 1 newton ampere^{-1} metre^{-1} (NA^{-1}m^{-1}) = 1 weber metre^{-2} (Wb m^{-2})

The **cgs unit** is gauss (G), 1 gauss (G) = 10^{-4} tesla (T).

Magnetic Field Lines

A line such that the tangent at any point on it gives the direction of the magnetic field at that point is called a magnetic field line or magnetic lines of force.

Properties of Magnetic Field Lines

(i) All field lines are closed curves. They come out of the magnet from the side of the north pole and go into it on the side of the south pole. They continue inside the magnet.

(ii) The field lines are close together near the poles and spread out away from them.

(iii) Two field lines never intersect each other.

ACTIVITY: Mapping of Magnetic Lines of Force

- Fix a sheet of white paper on a drawing board using some adhesive material. • Place a bar magnet in the centre of it.
- Sprinkle some iron filings uniformly around the bar magnet. A salt-sprinkler may be used for this purpose.
- Now tap the board gently. The iron filings rearrange themselves in the form of curves.

The curves represent the magnetic lines of force.

MAGNETIC FIELD DUE TO MAGNETIC POLE

In SI, the magnetic induction $\vec{B}$ due to a magnetic pole at a point at a distance r is defined as the force per unit north pole placed there, having the magnitude

$$B = \left(\frac{\mu}{4\pi}\right)\left(\frac{m}{r^2}\right) \text{ tesla} \quad \Rightarrow \quad H = \frac{B}{\mu} = \left(\frac{1}{4\pi}\right)\left(\frac{m}{r^2}\right) \text{ A/m}$$

And direction away for north pole and towards for the south pole.

In CGS, the magnetic field intensity $\vec{H}$ due to a magnetic pole at a point at a distance r is defined as the force per unit north pole placed there, having the magnitude

$$H = \left(\frac{1}{\mu}\right)\left(\frac{m}{r^2}\right) \text{oersted} \Rightarrow B = \mu H = \left(\frac{m}{r^2}\right) \text{gauss}$$

And direction away for the north pole and towards for the south pole.

FORCE ON MAGNETIC POLE PLACED IN MAGNETIC FIELD

In SI, the force on a magnetic pole of strength m placed in a magnetic field $\vec{B}$ is $\vec{F} = \pm m\vec{B}$

where + sign is for the north pole and – sign is for the south pole. Thus, the force is in the direction of $\vec{B}$ for the north pole and in the opposite direction for the south pole

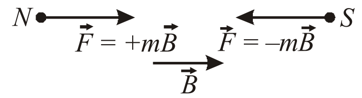


Fig. 4.12

In CGS, the force on a magnetic pole of strength m placed in a magnetic field $\vec{H}$ is $\vec{F} = \pm m\vec{H}$

where + sign is for the north pole and – sign is for the south pole. Thus, the force is in the direction of $\vec{H}$ for the north pole and in the opposite direction for the south pole.

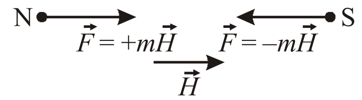


Fig. 4.13

CONNECTING TOPIC

BIOT-SAVART LAW

The Biot-Savart law defines the magnetic field $\vec{B}$ due to a current distribution. Let us consider a line distribution of steady current I confined to a filamentary wire ST. The wire may be imagined to be subdivided into the many elementary parts, each characterised by a vector $d\vec{l}$ whose magnitude is equal to the length of elementary part and whose direction is that of the current, as shown.

The magnetic field at a point P due to an elementary part is $d\vec{B} = \left(\frac{\mu_0 I}{4\pi}\right)\left(\frac{d\vec{l} \times \vec{R}}{R^3}\right)$

where $\vec{R}$ is the position vector of point P with respect to the elementary part. This magnetic field has the magnitude

$dB = \left(\frac{\mu_0 I}{4\pi}\right)\left(\frac{dl \sin\theta}{R^2}\right)$ this is **Biot-savart's law**

And the direction of the cross product $(d\vec{l} \times \vec{R})$, i.e., inwards and perpendicular to the plane of figure, as shown. The magnetic field $\vec{B}$ at the point P due to the complete wire ST is obtained by performing a summation process over all the elementary parts. The direction of $\vec{B}$ will be the same as that of an elementary magnetic field $d\vec{B}$.

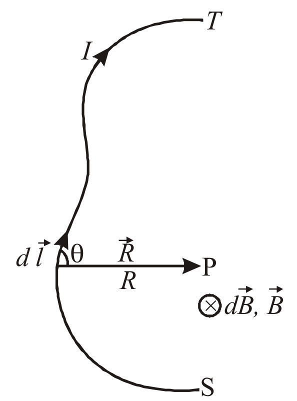


Fig. 4.14

MAGNETIC FIELD DUE TO A CURRENT CARRYING CONDUCTOR

From Oersted experiment followed by Ampere we can conclude that a magnetic field is developed around a conductor when electric current is passed through it. This observation is called magnetic effect of electric current. The presence of a current in a wire near a magnetic compass affect the direction of the compass needle. We now know that current gives rise to magnetic fields, just as electric charge give rise to electric fields.

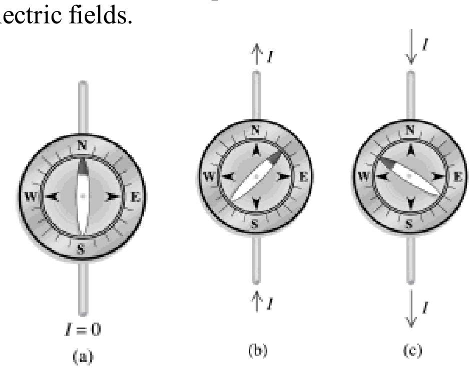


Fig. 4.15 : Compass near a current-carrying wire

Magnetic Field due to a Current Through a Straight Conductor

The magnetic field around a conductor carrying current is in the form of closed circular loops, in a plane perpendicular to the conductor, and is given by right hand thumb rule.

Right Hand Thumb Rule

If we grasp the conductor in the palm of the right hand so that the thumb points in the direction of the flow of current, then the direction in which the fingers curl, gives the direction of magnetic field lines.

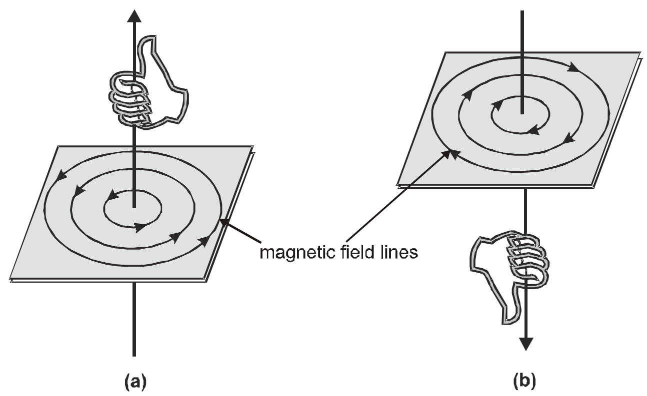


Fig. 4.16

For the current flowing through the conductor in the direction shown in figures (a) or (b), the rule predict that magnetic field lines will be in anticlockwise direction, when seen from above.

This rule is also called Maxwell's corkscrew rule. If we consider ourselves driving a corkscrew in the direction of the current, then the direction of the corkscrew is the direction of the magnetic field.

Ampere's Swimming Rule

Imagine a man swimming along the wire, in the direction of current, (such that the current enters at his feet and leaves him at his head) and facing towards a compass needle placed underneath the wire, then the magnetic field produced is such that the north pole of the compass needle gets deflected towards his left hand.

Knowledge ENHANCER

Magnetic field due to long straight conductor

$$B = \frac{\mu_0 I}{4\pi r}(\sin\theta_1 + \sin\theta_2) \qquad \frac{\mu_0}{4\pi} = 10^{-7}\,\frac{\text{tesla} - m}{\text{amp.}}$$

If the conductor is infinitely long, then $\theta_1 = 90°$ and $\theta_2 = 90°$

$$B = \frac{\mu_0 I}{4\pi r}\left[\sin\frac{\pi}{2} + \sin\left(\frac{\pi}{2}\right)\right] = \frac{\mu_0 I}{4\pi r}[1+1]\frac{\mu_0}{4\pi}\frac{2I}{r}$$

or $\quad B = \dfrac{\mu_0 I}{2\pi r}$

If conductor is of infinite length but one end is in front of point P i.e. one end of conductor starts from point N then

$\theta_1 = 0°$ and $\theta_2 = 90°$ $\therefore$ $B = \dfrac{\mu_0 I}{4\pi r}$

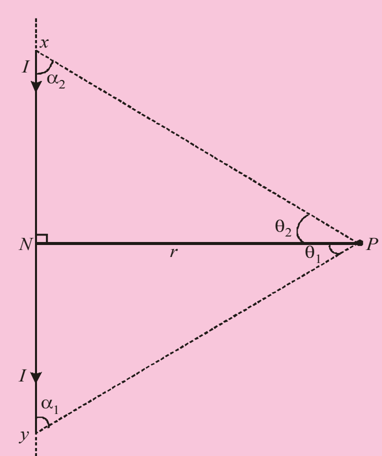


Fig. 4.17

Conductor is finite length and point P is just in front of middle of the conductor

$$B = \frac{\mu_0 I}{4\pi r}(2\sin\theta) \qquad [\theta_1 = \theta_2 = \theta]$$

$$B = \frac{\mu_0 I L}{2\pi r\sqrt{L^2 + r^2}} \qquad \sin\theta = \frac{L/2}{\sqrt{\left(\frac{L}{2}\right)^2 + r^2}}$$

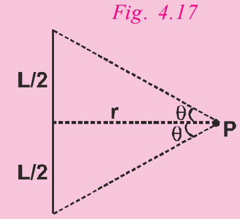


Fig. 4.18

ILLUSTRATION : 4.2

Compute the magnetic field at a point of 9 cm from the long straight wire carrying a current of 6A.

SOLUTION :

Here, $a = 9\text{ cm} = 9 \times 10^{-2} m, I = 6A, B = ?$

$$B = \frac{\mu_o I}{2\pi a} = \frac{4\pi \times 10^{-7} \times 6}{2\pi \times 9 \times 10^{-2}} = 1.33 \times 10^{-5}\text{T}$$

Magnetic Field Due to a Current Through a Circular Loop

At every point of a current-carrying circular loop, the concentric circles representing the magnetic field around it would become larger and larger as we move away from the wire. By the time we reach at the centre of the circular loop, the arcs of these big circles would appear as straight lines. Every point on the wire carrying current would give rise to the magnetic field appearing as straight lines at the center of the loop. By applying the right hand rule, it is easy to check that every section of the wire contributes to the magnetic field lines in the same direction within the loop.

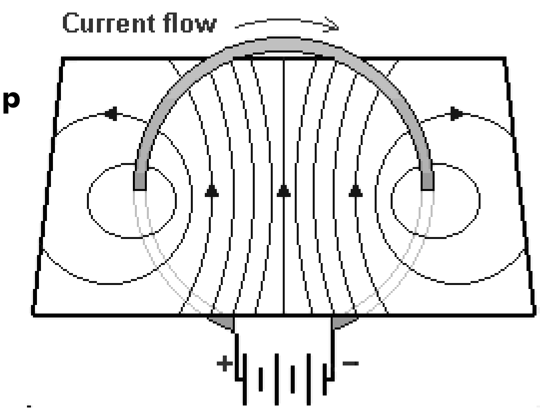


Fig. 4.19

Knowledge ENHANCER

Magnetic field at the centre of a circular current-carrying coil

$$B = \frac{\mu_0 I}{2r} \quad \text{For a coil of n turns,} \quad B = \frac{\mu_0 nI}{2r}$$

Magnetic Field due to part of current carrying circular conductor (Arc)

$$B = \frac{\mu_0 I}{4\pi r}\alpha$$

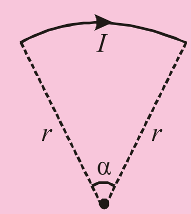


Fig.4.20

Magnetic field on the axis of a circular coil

$$B = \frac{\mu_0 \, N\, I\, a^2}{2(a^2 + x^2)^{3/2}}$$

At the centre of the loop, $x = 0$

$$B = \frac{\mu_0 \, N\, I\, a^2}{2\, a^3} \qquad or \qquad B = \frac{\mu_0 \, N\, I}{2\, a}$$

In terms of area A $(= \pi a^2)$ of the circular current loop, the quantity N I A is known as the magnetic dipole moment M of the current loop.

Magnetic dipole moment of the current loop

The current loop can be regarded as a magnetic dipole which produces its magnetic field and magnetic dipole moment of the current loop is equal to the product of ampere turns and area of current loop, we can write

$$B = \frac{\mu_0 \, N\, I\, A}{2\, r(\pi\, a^2)} = \frac{\mu_0}{2\pi}\frac{N\, I\, A}{a^3} \quad or \quad B = \frac{\mu_0}{4\pi}\frac{2\,\text{N I A}}{\text{a}^3}$$

$$\therefore \quad B = \frac{\mu_0}{4\pi}\frac{2M}{a^3}$$

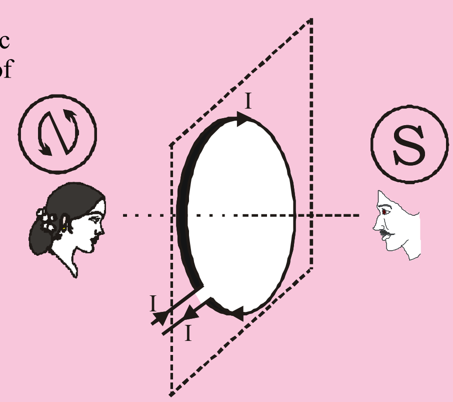


Fig. 4.21

If the observation point is far away from the coil, then $a << x$.
So, a^2 can be neglected in comparison to x^2.

$$\therefore \quad B = \frac{\mu_0 \, N\, I\, a^2}{2x^3}$$

In terms of magnetic dipole moment, $B = \dfrac{\mu_0}{4\pi}\dfrac{2\, M}{x^3}$ $\qquad \left[B = \dfrac{\mu_0}{2\pi}\dfrac{N\, I\, A}{x^3} = \dfrac{\mu_0}{4\pi}\dfrac{2\, N\, I\, A}{x^3} \right]$

RIGHT HAND PALM RULE

If we hold the thumb of right hand mutually perpendicular to the grip of the fingers such that the curvature of the finger represents the direction of current in the wire loop, then the thumb of the right hand will point in the direction of magnetic field near the centre of the current loop.

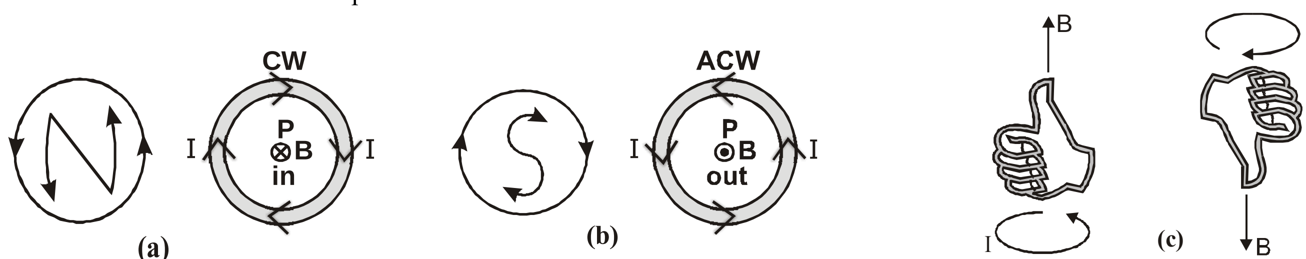


Fig. 4.22

ILLUSTRATION : 4.3

An infinite straight conductor carrying current $2I$ is split into a loop of radius r as shown in figure. The magnetic field at the centre of the coil is

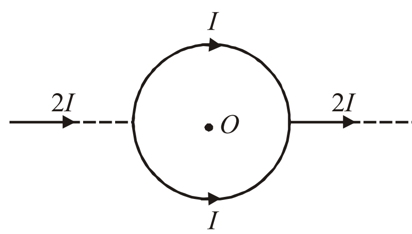


Fig. 4.23

(a) **Zero** (b) $\frac{\mu_0 I}{2}$ (c) $\mu_0 I$ (d) $2\mu_0 I$

SOLUTION :

(a) Here, the wire does not produce any magnetic field at O because the conductor lies on the line of O. Also, the loop does not produce magnetic field at O.

ILLUSTRATION : 4.4

A current of I ampere flows in a wire forming a circular arc of radius r metres subtending an angle θ at the centre as shown. what will be the magnetic field at the centre O in tesla?

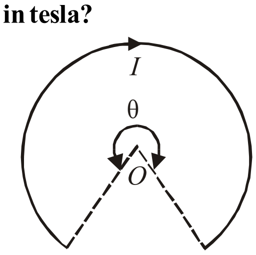


Fig. 4.24

SOLUTION :

Magnetic field at the centre 'O' $B = \frac{\mu_0 I}{2r} \times \frac{\theta}{2\pi} = \frac{\mu_0 I\theta}{4\pi r}$

ILLUSTRATION : 4.5

A long conducting wire, carrying a current I, is arranged in the shape, as shown, with the two straight segments in the plane of figure and the circular loop of radius r perpendicular to the plane of figure. Calculate the magnetic field at the centre O of the circular loop.

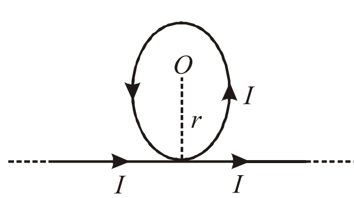


Fig. 4.25

SOLUTION :

The magnetic field at the centre O of the circular loop due to the two straight segments, taken together, will be

$$B_1 = 2\left(\frac{\mu_0 I}{4\pi r}\right)$$

which is perpendicular to the plane of figure and outwards, according to the 'Right-Hand Rule'.

The magnetic field at the centre O due to the circular loop will be

$$B_2 = \left(\frac{\mu_0 I}{2r}\right)$$

which is parallel to the straight segments and towards right. Since, the two magnetic fields B_1, B_2 are mutually perpendicular, the resultant magnetic field at the centre O is given by

$$B = \sqrt{B_1^2 + B_2^2} = \left(\frac{\mu_0 I}{2r}\right)\sqrt{\left(\frac{1}{\pi^2}+1\right)}$$

CONNECTING TOPIC

MAGNETIC FIELD DUE TO A BAR MAGNET

End-on Position

The magnetic field $\vec{B}$ at a point P on the axis of a bar magnet at distance r form it's mid point O is given by

$$\vec{B} = \vec{B}_N + \vec{B}_s \qquad \Rightarrow \qquad B = B_N - B_S$$

$$= \left(\frac{\mu}{4\pi}\right)\frac{m}{(r-l)^2} - \frac{\mu}{4\pi}\frac{m}{(r+l)^2}$$

$$= \left(\frac{\mu}{4\pi}\right)\frac{2Mr}{(r^2-l^2)^2} \approx \left(\frac{\mu}{4\pi}\right)\left(\frac{2M}{r^3}\right) \text{ for } l << r$$

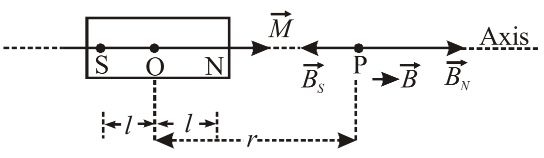


Fig. 4.26

which is having the direction parallel to the magnetic moment $\vec{M}$ of the bar magnet.

Broadside-on Position

The magnetic field $\vec{B}$ at a point P on the equator of the bar magnet at a distance r from it's mid point O is given by

$$\vec{B} = \vec{B}_N + \vec{B}_s$$

$$\Rightarrow \quad B = 2B_N \cos\theta = 2B_s \cos\theta$$

$$= 2\left(\frac{\mu}{4\pi}\right)\frac{m}{(r^2+l^2)}\cdot\frac{l}{\sqrt{(r^2+l^2)}}$$

$$= \left(\frac{\mu}{4\pi}\right)\frac{M}{(r^2+l^2)^{3/2}} \approx \left(\frac{\mu}{4\pi}\right)\left(\frac{M}{r^3}\right) \text{ for } l << r$$

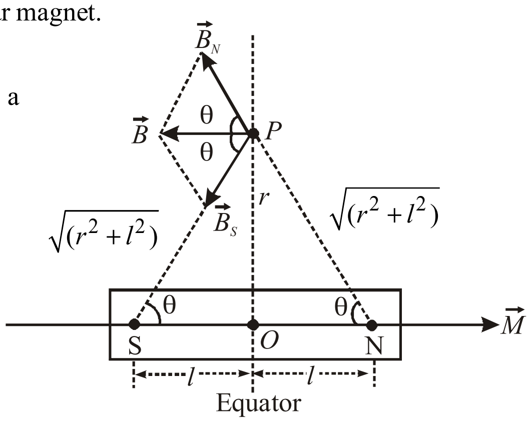


Fig. 4.27

which is having the direction antiparallel to the magnetic moment $\vec{M}$ of the bar magnet. Evidently, the magnetic field at the broadside-on position is one-half of that at the end-on position for the same distance r from the mid point O of the bar magnet.

Any other position

The magnetic moment $\vec{M}$ of bar magnet has the two components, namely, $M\cos\theta$ and $M\sin\theta$, as shown. The point P is neither on the axis nor on the equator of bar magnet but having any other position at a distance r from the mid point O. It's position is end-on for the component $M\cos\theta$ and broadside-on position for the component $M\sin\theta$. Therefore, the magnetic field $\vec{B}$ at the point P is given by

$$\vec{B} = \vec{B}_r + \vec{B}_\theta$$

$$\Rightarrow \quad B = \sqrt{(B_r^2 + B_\theta^2)}$$

$$= \sqrt{\left[\left(\frac{\mu}{4\pi}\right)^2\left(\frac{2M\cos\theta}{r^3}\right)^2 + \left(\frac{\mu}{4\pi}\right)^2\left(\frac{M\sin\theta}{r^3}\right)^2\right]}$$

$$= \left(\frac{\mu}{4\pi}\right)\left(\frac{M}{r^3}\right)\sqrt{(4\cos^2\theta + \sin^2\theta)}$$

$$= \left(\frac{\mu}{4\pi}\right)\left(\frac{M}{r^3}\right)\sqrt{(1 + 3\cos^2\theta)}$$

whose direction is inclined at an angle $(\phi + \theta)$ with the magnetic moment $\overrightarrow{M}$, where

$$\tan\phi = \frac{B_\theta}{B_r} = \left(\frac{1}{2}\right)\tan\theta$$

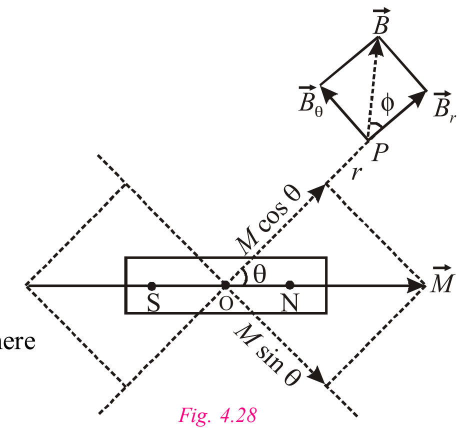


Fig. 4.28

FORCE ON A CURRENT CARRYING CONDUCTOR IN A MAGNETIC FIELD

For a conductor of length L carrying a current of I in a field B the force experienced by the conductor $\vec{F} = I\,\vec{L} \times \vec{B}$
Direction of force can be determined by fleming's left hand rule, right hand palm rule or screw rule.

Fleming's Left-Hand Rule

Stretch the fore-finger, central finger and thumb of left hand mutually perpendicular.

Then if the fore-finger points in the direction of field $(\vec{B})$, the central finger in the direction of current (I), the thumb will point in the direction of force Fig. 4.29.

Right-Hand Palm Rule

Stretch the fingers and thumb of right hand at right angles to each other. Then if the fingers point in the direction of field $(\vec{B})$ and thumb in the direction of current I, the normal to palm will point in the direction of force Fig. 4.30.

Screw Rule

Curl right hand finger from current towards magnetic field thumb will give the direction of force as shown in figure 4.31.

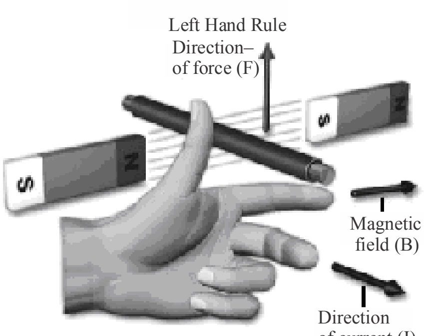


Fig. 4.29

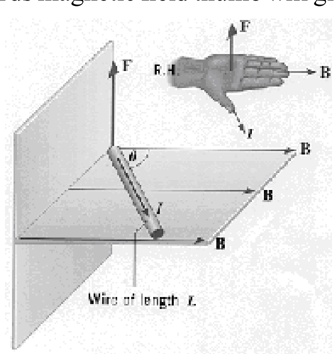


Fig. 4.30

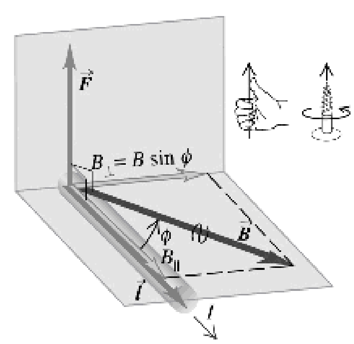


Fig. 4.31 : Magnetic force on straight wire segment.

You can see component of magnetic field perpendicular to current contributes in force on conductor. If current in wire is along external magnetic field force will be zero and if perpendicular to field it will be maximum.

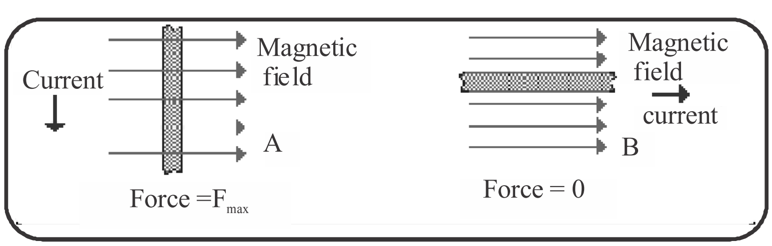


Fig. 4.32

If direction of current or field reverses, direction of force also reverses as shown in figure 4.33

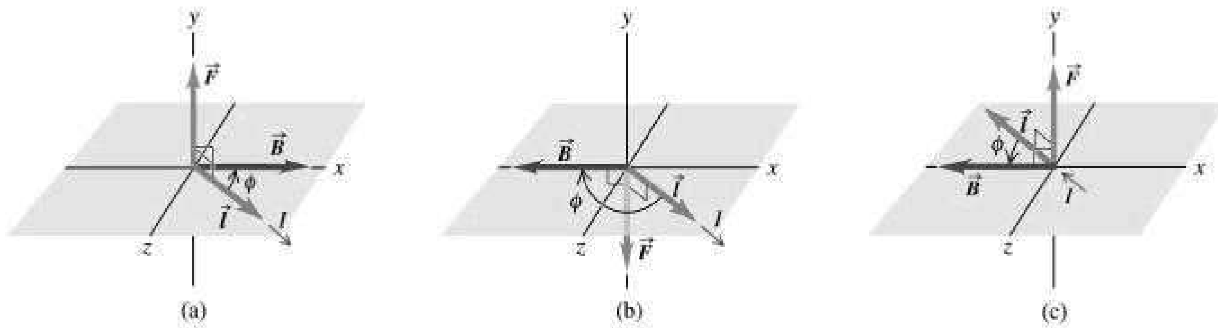


Fig. 4.33 : Magnetic forces - reversing the direction of the field B or the direction of the current I reverses the direction of the force.

Any arbitrary shape in a uniform field experience a force

$$\vec{F} = I\vec{\ell'} \times \vec{B}$$

where $\vec{\ell'}$ is the length vector joining initial and final points of the conductor as shown in figure.

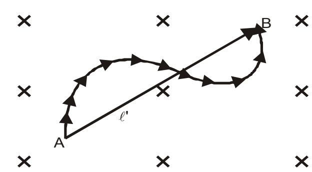
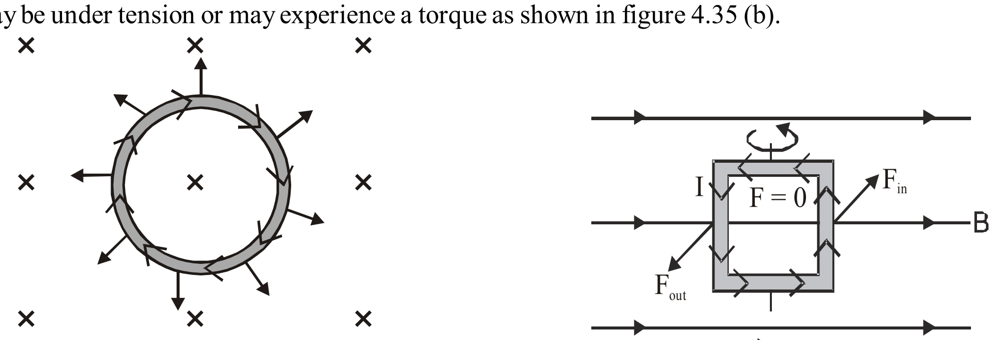


Fig. 4.34

If the current-carrying conductor in the form of a loop of any arbitrary shape is placed in a uniform field, then, $\vec{F} = 0$
i.e., the net magnetic force on a current loop in a uniform magnetic field is always zero as shown in figure 4.35 (a).
Here it must be kept in mind that in this situation different parts of the loop may experience elemental force due to which the loop may be under tension or may experience a torque as shown in figure 4.35 (b).



(a) $\vec{F} = 0$
$\vec{\tau} = 0$

(b) $\vec{F} = 0$
$\vec{\tau} \neq 0$

Fig. 4.35

ILLUSTRATION : 4.6

A vertical straight conductor X of length 0.5 m is situated in a uniform horizontal magnetic field, of 0.1T (i) calculate the force on X when a current of 4A is passed into it (ii) through what angle must X be turned in a vertical plane so that the force on X is halved ?

Solution :

(i) Here, L = 0.5 m, B = 0.1T, I = 4A, F = ?
F = BIL = 0.1 × 4 × 0.5 = 0.2N

(ii) Let α be the required angle.
The force on the conductor

$$F' = \frac{1}{2}F\frac{0.2}{2} = 0.1\text{N}$$

$$F' = BIL\ \text{Sin}\theta$$

$$\text{or, } \frac{1}{2}\text{BIL} = \text{BILSin}(90° - \alpha)$$

$$\text{or, } \frac{1}{2}\cos\alpha \text{ or } \alpha = \cos^{-1}\left(\frac{1}{2}\right) = 60°$$

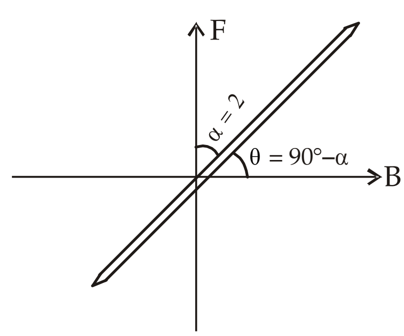


Fig. 4.36

CONNECTING TOPIC

FORCE ON A CHARGED PARTICLE IN A MAGNETIC FIELD

According to Lorentz , charge particle q moving with velocity v in a magnetic field B experiences

Force, $\vec{F} = q\,(\vec{v}\times\vec{B})$

The force $\vec{F}$ is always perpendicular to both the velocity $\vec{v}$ and the field $\vec{B}$.
A charged particle at rest in a steady magnetic field does not experience any force.

If the charged particle is at rest then $\vec{v} = 0$, so $\vec{v} \times \vec{B} = 0$
A moving charged particle does not experience any force in a magnetic field if its motion is parallel or antiparallel to the field.
i.e., if $\theta = 0°$ or $180°$,

then, $|\vec{F}| = q\,v\,B\sin\theta = 0$ $[\because \sin 0° = 0 \text{ and } \sin 180° = 0]$

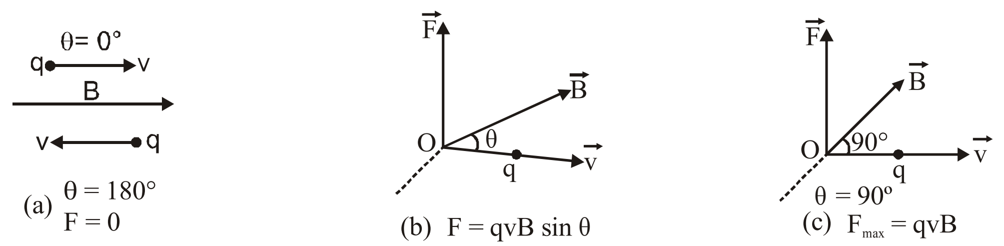


Fig. 4.37

If the particle is moving perpendicular to the field

In this situation all the three vectors $\vec{F}$, $\vec{v}$ and $\vec{B}$ are mutually perpendicular to each other.
Then $\sin\theta = \max = 1$, i.e., $\theta = 90°$,
The force will be maximum $F_{max} = q\,v\,B$
Work done by force due to magnetic field in motion of a charged particle is always zero.
When a charged particle moves in a magnetic field, then force acts on it is always perpendicular to displacement,

so the work done, $W = \vec{F}.\vec{s} = Fs\cos\theta = 0$ (as $\theta = 90°$),

And as by work-energy theorem $W = \Delta$ KE, the kinetic energy $(= \frac{1}{2}mv^2)$ remains unchanged and hence speed of charged particle v remains constant.
However, in this situation the force changes the direction of motion, so the direction of velocity $\vec{v}$ of the charged particle changes continuously.
The direction of the cross product can be obtained by using a **right-hand rule**:
Fingers of the right hand point in the direction of the first vector (v) in the cross product, then adjust your wrist so that you can bend your fingers (at the knuckles) toward the direction of the second vector (B); extend the thumb to get the direction of the force.

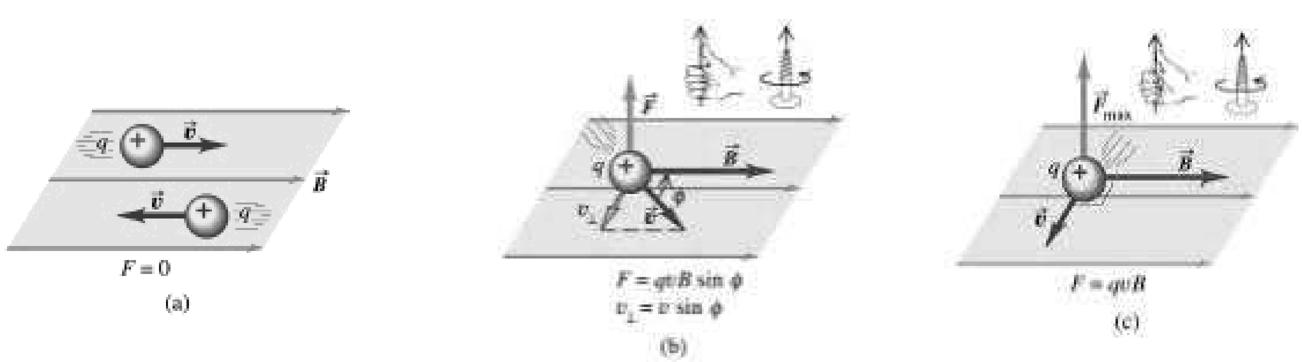


Fig. 6.38 : Magnetic force acting on a moving charge.

A charged particle moving in a plane perpendicular to a magnetic field will move in a circular orbit with the magnetic force playing the role of centripetal force.
The direction of the force is given by the right-hand rule. Equating the centripetal force with the magnetic force and solving for R the radius of the circular path we get,

$mv^2 / R = q\,v\,B$ and $R = m\,v / q\,B$

If charge particle projected at some angle with magnetic field, it will move on helical path.

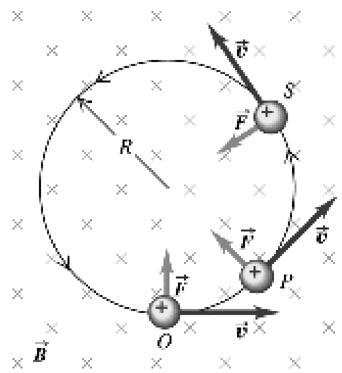
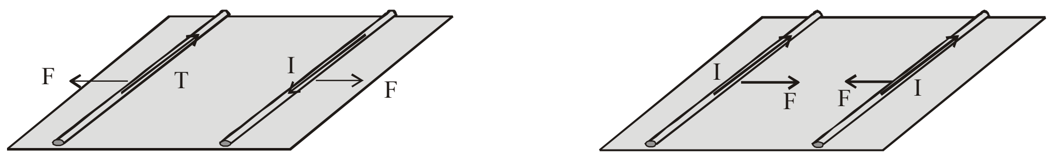


Fig. 4.39 : Orbit of charged particle in a magnetic field.

FORCE BETWEEN CURRENT CARRYING WIRES

If currents through two wires placed parallel are in the same direction, they attract. If current flow in opposite direction, wires repel. This is the opposite of the rule for charges: like charges repel, opposite charges attract. Using the two right hand rules, one for finding the direction of the B-field of a wire, and the other for the direction of force on a wire, you can predict the results.



(a) Repulsion (b) Attraction

Fig. 4.40

The force per unit length on one wire due to other wire

$\dfrac{F}{\ell} = \dfrac{\mu_0 I_1 I_2}{2\pi d}$ [where I_1, I_2 current in two wires and d = distance between wires]

Definition of Ampere

As, $F = \dfrac{\mu_0}{2\pi}\,\dfrac{I_1 I_2}{r}$ N/m

When $I_1 = I_2 = 1$ ampere and r = 1m, then $F = \dfrac{\mu_0}{2\pi} = \dfrac{4\pi \times 10^{-7}}{2\pi}$ N/m $= 2 \times 10^{-7}$ N/m

This leads to the following definition of ampere.
One ampere is that current which, if passed in each of two parallel conductors of infinite length and one metre apart in vacuum causes each conductor to experience a force of 2×10^{-7} newton per metre of length of conductor.

FORCE AND TORQUE ON BAR MAGNET PLACED IN MAGNETIC FIELD

Uniform Magnetic Field

When a bar magnet is placed in a uniform magnetic field $\vec{B}$ at an angle θ, the total force on it becomes

$$\vec{F} = \vec{F}_N + \vec{F}_S = (+m)\;(+m)\vec{B} + (-m)\vec{B} = 0$$

and hence, it does not undergo any translatory motion.

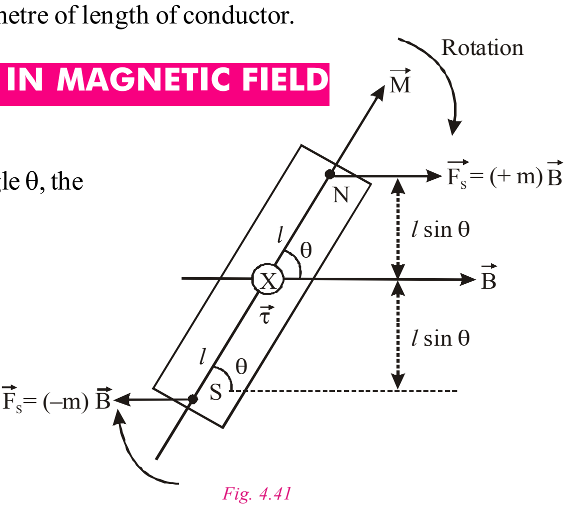


Fig. 4.41

The total torque on the bar magnet due to the magnetic field is

$\vec{\tau} = \vec{M} \times \vec{B}$ whose magnitude is

$$\tau = (mB)\,l\sin\theta + (mB)\,l\sin\theta$$
$$= (2ml)\,B\sin\theta = MB\sin\theta$$

and whose direction is perpendicular to the plane of figure and inwards, as shown. This torque produces the rotatory motion of the bar magnet in the clockwise direction.

Non-uniform Magnetic Field

When the bar magnet is placed in a non-uniform magnetic field $\vec{B}$ at an angle θ, the total force on it becomes

$$\vec{F} = \vec{F}_N + \vec{F}_S$$

$$= (+m)\,\vec{B} + (-m)\vec{B}' = m(\vec{B} - \vec{B}') \neq 0$$

which produces the translatory motion of the bar magnet in its' direction. The total torque on the bar magnet due to the magnetic field is

$\vec{\tau} = \vec{M} \times \vec{B}_{av}$ whose magnitude is

$$\tau = (mB)\,l\sin\theta + (mB')\,l\sin\theta$$

$$= (2ml)\left(\frac{B+B'}{2}\right)\sin\theta = MB_{av}\sin\theta$$

where B_{av} is the average magnetic field, and whose direction is perpendicular to the plane of figure and inwards, as shown. This torque produces the rotatory motion of the bar magnet in the clockwise direction.

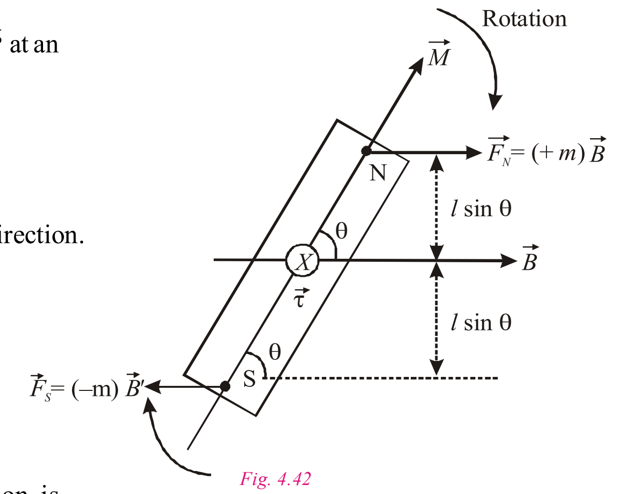


Fig. 4.42

ELECTROMAGNET

A magnetic field is produced when an electric current flows through a coil of wire. This is the basis of the electromagnet. We can make an electromagnet stronger by doing these things:

- Adding more turns to the coil.
- Increasing the current flowing through the coil.

The magnetic field around an electromagnet is just the same as the one around a bar magnet. It can, however, be reversed by turning the battery around. Unlike bar magnets, which are permanent magnets, the magnetism of electromagnets can be turned on and off just by closing or opening the switch. Electromagnets are temporary magnets.

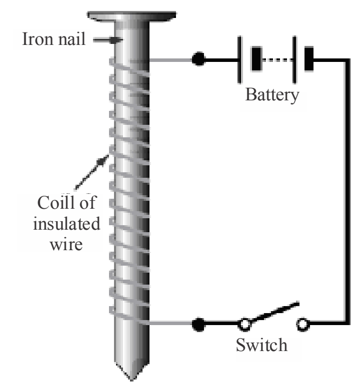


Fig. 4.43 : A simple electromagnet.

Uses of Electromagnet

1. For lifting and transporting large masses of iron scrap, girders, plates etc., especially to places where it is not convenient to take the help of human labour. Electromagnets are used to lift as much as 20-22 tonnes of iron in a single lift. To unload the magnet at the desired place, the current in the electromagnet is switched off so that the load drops.
2. For loading furnaces with iron.
3. For separating magnetic substances such as iron from other debris (e.g. for separating iron from the crushed copper ore in copper mines).
4. For removing pieces of iron from wounds.
5. In several electrical devices such as electric-bell, telegraph, electric tram, electric motor, relay, microphone, loud speaker, etc.
6. In scientific research to study the magnetic properties of a substance in a magnetic field.

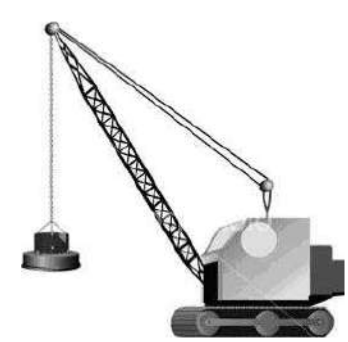


Fig. 4.44 : Electric Crane.

DC AND AC ELECTRIC MOTOR

D.C. Motor

An electric motor converts electrical energy into mechanical energy. A d.c. motor converts direct current energy from a battery into mechanical energy of rotation.

Principle : It is based on the fact that when a coil carrying current is held in a magnetic field, it experiences a torque, which rotates the coil.

Construction : It consists of the five parts.

1. Armature : The armature coil ABCD consists of a large number of turns of insulated copper wire wound over a soft iron core.

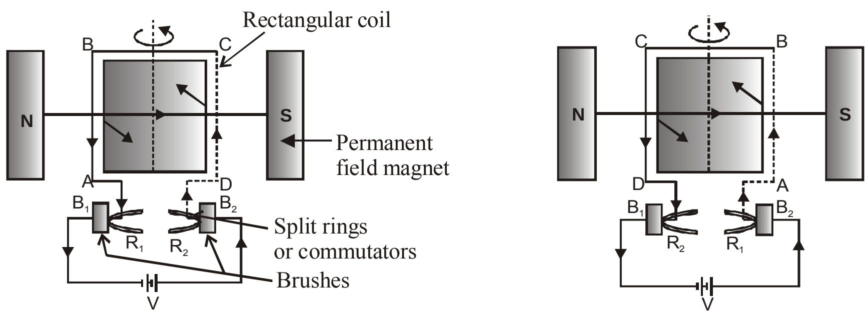
2. Field magnet : The magnetic field is supplied by a permanent magnet NS.

3. Split-rings or commutator : These are two halves of the same ring. The ends of the armature coil are connected to these halves which also rotate with the armature.

4. Brushes : These are two flexible metal plates or carbon rods B_1 and B_2, which are so fixed that they constantly touch the revolving rings.

5. Battery : The battery consists of a few cells of voltage V connected across the brushes. The brushes convey the current to the rings, from where it is carried to the armature.

Working : The battery sends current through the armature coil in the direction shown in figure. Applying Fleming's Left Hand rule, CD experiences a force directed inwards and perpendicular to the plane of the coil. Similarly, AB experiences a force directed outwards and perpendicular to the plane of the coil. These two forces being equal, unlike and parallel form a couple. The couple rotates the armature coil in the anticlockwise direction. After the coil has rotated through 180°, the direction of the current in AB and CD is reversed, figure. Now CD experiences an outward force and AB experiences an inward force. The armature coil thus continues rotating in the same i.e., anticlockwise direction.



(a) **(b)**

Fig. 4.45

Efficiency of the d.c. motor :

Since the current I is being supplied to the armature coil by the external source of e.m.f. V, therefore,

Input electric power = VI

According to Joule's law of heating, Power lost in the form of heat in the coil = $I^2 R$

If we assume that there is no other loss of power, then Power converted into external work i.e.,

Output mechanical power = $VI - I^2 R = (V - IR) I = EI$

$\therefore$ Efficiency of the d.c. motor, $\eta = \dfrac{\text{Output mechanical power}}{\text{Input electric power}}$

A d.c. motor delivering maximum output has an efficiency of only 50%.

Uses : (i) The d.c. motors are used in d.c. fans (exhaust, ceiling or table) for cooling and ventilation.

(ii) They are used for pumping water.

(iii) Big d.c. motors are used for running tram-cars and even trains.

A.C. Motor

As in the DC motor case, a current is passed through the coil, generating a torque on the coil. Since the current is alternating, the motor will run smoothly only at the frequency of the *sine* wave. It is called a synchronous motor. More common is the induction motor, where electric current is induced in the rotating coils rather than supplied to them directly.

One of the drawbacks of this kind of AC motor is the high current which must flow through the rotating contacts. Sparking and heating at those contacts can waste energy and shorten the lifetime of the motor. In common AC motors the magnetic field is produced by an electromagnet powered by the same AC voltage as the motor coil. The coils which produce the magnetic field are sometimes referred to as the "stator", while the coils and the solid core which rotates is called the "armature". In an AC motor the magnetic field is sinusoidally varying, just as the current in the coil varies.

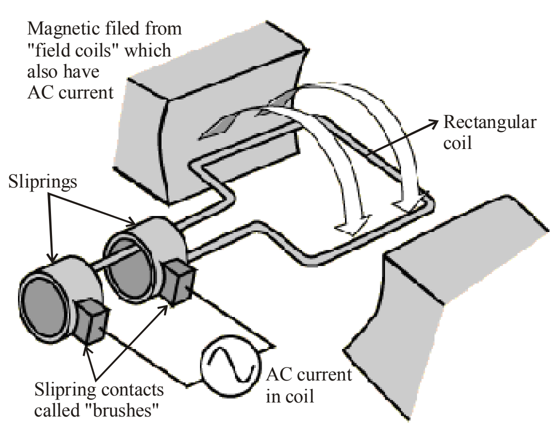
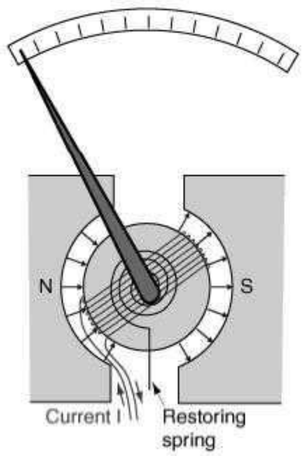


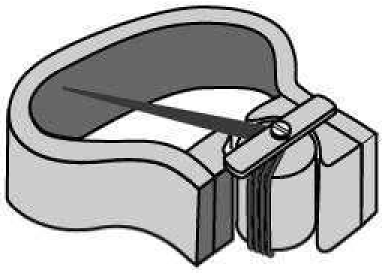
Fig. 4.46

Galvanometer

The torque on a current loop in a uniform magnetic field is used to measure electrical magnetic field is used to measure electrical currents. This current measuring device is called a moving coil galvanometer.



(a)



(b)

Fig. 4.47

The galvanometer consists of a coil of wire often rectangular, carrying the current to be measured. There are generally many turns in the coil to increase its sensitivity. The coil is placed in a magnetic field such that the lines of B remain nearly parallel to the plane of wire as it turns. This is achieved by having a soft iron cylinder placed at the center of the coil. Magnetic field lines tend to pass through the iron cylinder, producing the field configuration. The moving coil is hung from a spring which winds up as the coil rotates; this winding up produces a restoring torque proportional to the winding up (or twisting) of the spring, i.e. to the angular deflection of the coil. The coil comes to equilibrium when this restoring torque k balances the torque due to the magnetic field balances the torque due to the magnetic field.

CHECK *Point*

How could a light bulb near, yet not touching, an electromagnet be lit? Is AC or DC required? Defend your answer.

SOLUTION

For the bulb to be lit, AC should be supplied in the coil of the electromagnet so that an alternating magnetic field will be established in the region around it. This changing magnetic field will induce a current in the circuit of the light bulb and the bulb will glow.

ELECTROMAGNETIC INDUCTION

In the early 1800s, the only current-producing devices were voltaic cells, which produced small currents by dissolving metals in acids. These were the forerunners of our present-day batteries. The question arose as to whether electricity could be produced from magnetism. The answer was provided in 1831 by two physicists, Michael Faraday in England and Joseph Henry in the United States—each working without knowledge of the other. Their discovery changed the world by making electricity commonplace—powering industries by day and lighting up cities at night.

Faraday and Henry both discovered that electric current could be produced in a wire simply by moving a magnet into or out of a coil of wire. (Figure 4.48(a)). No battery or other voltage source was needed—only the motion of a magnet in a wire loop. They discovered that voltage is caused, or *induced,* by the relative motion between a wire and a magnetic field. Whether the magnetic field moves near a stationary conductor or vice versa, voltage is induced either way (Figure 4.48(b)).

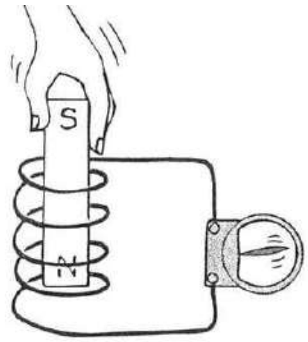


Fig. 4.48 (a), When the magnet is plunged into the coil, charges in the coil are set in motion, and voltage is induced in the coil.

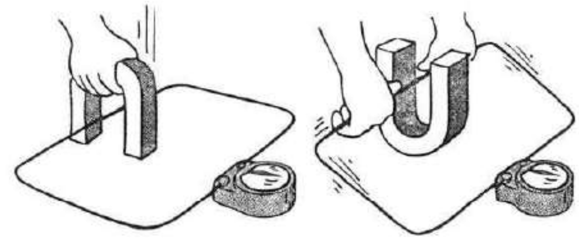


Fig. 4.48(b), Voltage is induced in the wire loop whether the magnetic field moves past the wire or the wire moves through the magnetic field.

The greater the number of loops of wire moving in a magnetic field, the greater the induced voltage (Figure 4.49). Pushing a magnet into a coil with twice as many loops induces twice as much voltage; Pushing into a coil with ten times as many loops induces ten times as much voltage; and so on. It may seem that we get something (energy) for nothing simply by increasing the number of loops in a coil of wire, but we do not.

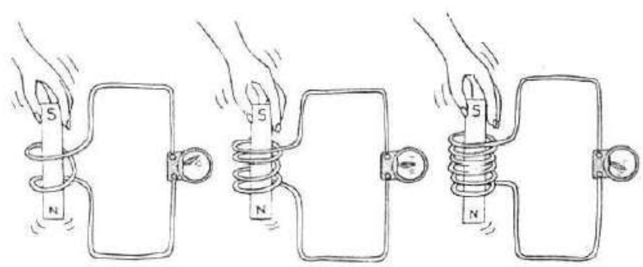


Fig. 4.49, When a magnet is plunged into a coil with twice as many loops as another, twice as much voltage is induced. If the magnet is plunged into a coil with three times as many loops, three times as much voltage is induced.

We find that it is more difficult to push the magnet into a coil made up of more loops. This is because the induced voltage produces a current, which makes an electromagnet, which repels the magnet in our hand. So we must do more work against this “back force” to induce more voltage (Figure 4.50).

Fig. 4.50, It is more difficult to push the magnet into a coil with many loops because the magnetic field of each current loop resists the motion of the magnet.

The amount of voltage induced depends on how fast the magnetic field lines are entering or leaving the coil. Very slow motion produces hardly any voltage at all. Rapid motion induces a greater voltage. This phenomenon of inducing voltage by changing the magnetic field in a coil of wire is called **electromagnetic induction.**

FARADAY'S EXPERIMENT

In 1831, Michael Faraday carried out numerous experiments in his attempt to prove that electricity could be generated from magnetism. Within the course of a few weeks, the great experimentalist not only had clearly demonstrated this phenomenon, now known as electromagnetic induction, but also had developed a good conception of the processes involved.

When a bar magnet is thrust into a coil connected to an electric circuit, a current is caused to flow in the circuit to which the coil is attached. If the magnet is withdrawn, the direction of the current is reversed. Such currents are called induced currents.

The size of the current depends on how fast the magnet moves in or out of the coil, and the number of loops in the coil.

The phenomenon of inducing a current by changing the magnetic field in a coil of wire is known as electromagnetic induction. This phenomenon underpins the design of all electric generators.

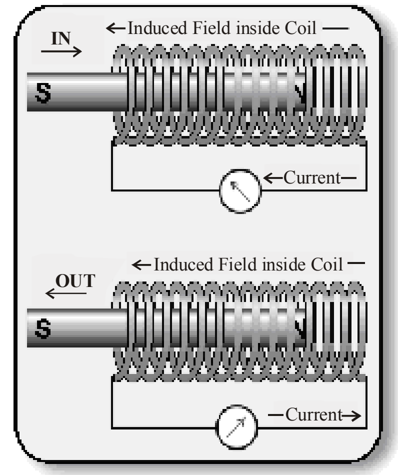
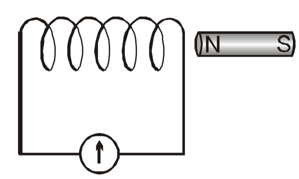
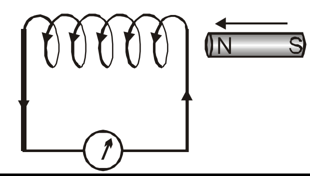
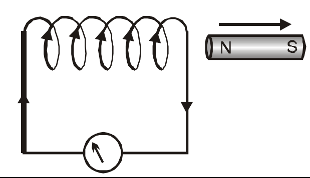
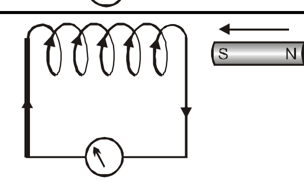
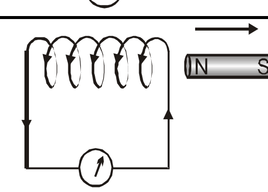


Fig. 4.51

FARADAY'S EXPERIMENT AND OBSERVATION

S. No.	Experiment	Observation	
1.	Place a magnet near a conducting loop with a galvanometer in the circuit	No current flows through the galvanometer	
2.	Move the magnet towards the loop	The galvanometer register a current	
3.	Reverse the direction of motion of the magnet	The galvanometer deflection reverses	
4.	Reverse the polarity of the magnet and move the magnet towards the loop	The galvanometer deflection reverses	
5.	Keep magnet fixed and move the coil towards the magnet	The galvanometer register a current	

6.	Increases the speed of the magnet	The deflection in the galvanometer increases
7.	Increase the strength of the magnet	The deflection in the galvanometer increases
8.	Increase the diameter of the coil	The deflection in the galvanometer increases
9.	Fix the speed of the magnet but repeat the experiment with the magnet closer to the coil.	The deflection in the galvanometer increases
10.	Move the magnet at an angle to the plane of the coil.	Deflection decreases, it is maximum when the magnet moves perpendicular to the plane of the coil and is zero when the magnet moves parallel to the plane of the coil.
11.	Increase the number of turns of the coil	Magnitude of current increases.

CONNECTING TOPIC

MAGNETIC FLUX

In analogy with the electric flux ϕ_E, a magnetic flux ϕ_B of the magnetic field for a surface is defined. Imagine dividing a surface into infinitesimal area elements. The direction of an area element $\overrightarrow{d_A}$ at a point on the surface is perpendicular to the surface at that point. A typical element for a surface is shown in fig. along with the magnetic field B at a point P.

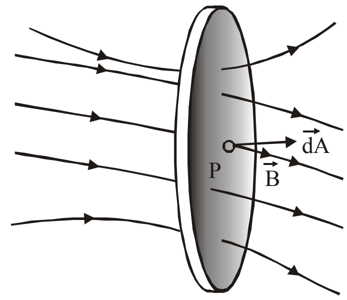
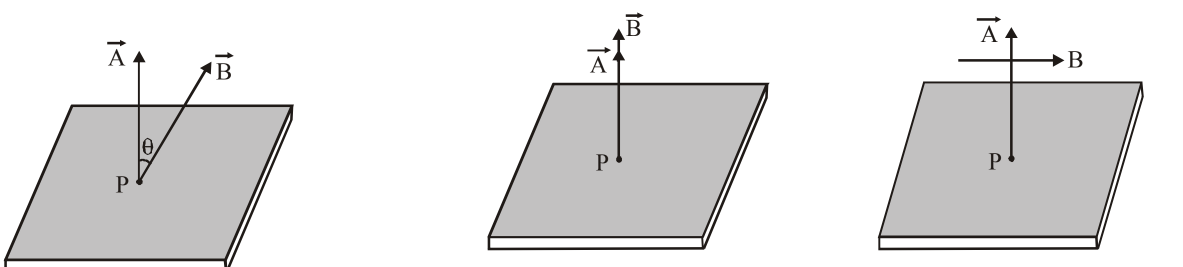


Fig. 4.52

The magnetic flux $d\phi$ for the area element "d_A" is $d\phi = \vec{B}.\overrightarrow{d_A}$.

If the magnetic field $\vec{B}$ makes an angle θ with the normal to the surface as shown in fig. then the normal component of the field is B cos θ and in this case, the magnetic flux is given by

$\phi = BA\cos\theta$ or $\phi = \vec{B}.\vec{A}$



(a) $\phi = BA\cos\theta$ (b) $\phi_{max} = BA$ (when $\theta = 0°$) (c) $\phi_{min} = 0$ (when $\theta = 90°$)

Fig. 4.53

So, *magnetic flux linked with a closed surface may be defined as the product of the surface area and the normal component of the magnetic field acting on that area. It may also be defined as the dot or scalar product of magnetic field and surface area.*

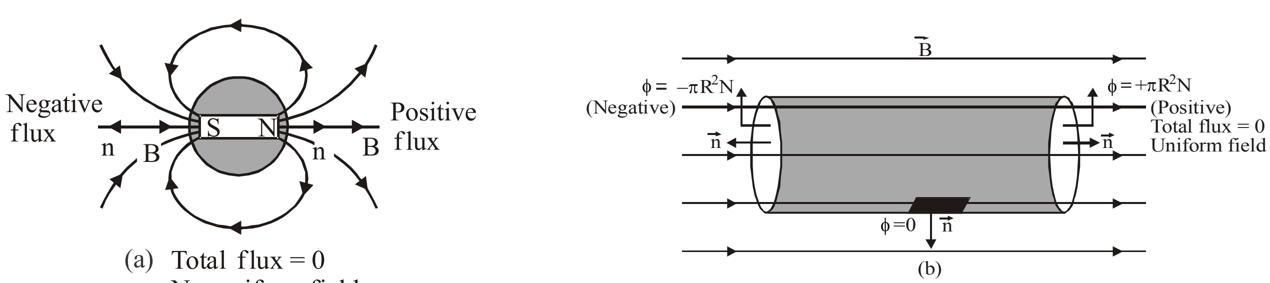
The magnetic flux for a general surface is obtained by integrating (summing) the contributions $d\phi$ as the area element dA ranges over the surface.

Thus, $\phi = \int \vec{B}.\overrightarrow{d_A}$

Physically it represents total lines of force passing through a given area.

Positive and Negative Flux

In case of a body present in a field, either uniform or non-uniform outward flux is taken to be positive while inward negative.



(a) Total flux = 0
Nonuniform field

(b)

Fig. 4.54

If the normal drawn on the surface is in the direction of the field, then the flux is taken as positive. In this case, θ is $0°$ or $\theta < 90°$. If the normal on the surface is opposite to the direction of the field, then $\theta = 180°$. In this case, the magnetic flux is taken as negative.

Magnetic flux density, $B = \frac{\phi}{A}$

Lines of force are imaginary, but as magnetic flux associated with elemental area $\overrightarrow{d_A}$ in a field $\vec{B}$, so flux is a real scalar physical quantity

S.I. unit of magnetic flux (ϕ) is weber (Wb)

The unit of magnetic field is tesla (T) or wb/m^2

Different Ways Which can Vary the Magnetic Flux

Magnetic flux in planar area $\vec{A}$ due to an uniform magnetic field $\vec{B}$, $\phi = BA\cos\theta$

So, flux linked with a circuit will change only if field B, area A, orientation θ or any combination of these changes.

(1) By varying the magnetic field $\vec{B}$ with time.

(2) By varying the area of the conducting loop $\vec{A}$ with time.

(3) Loop entering or leaving a finite region of magnetic field.

(4) Loop rotating in and out of a finite region of magnetic field.

(5) Effect of time varying angle between the area vector and the magnetic field vector .

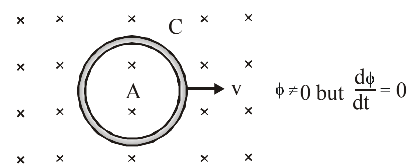


Fig. 4.55

FARADAY'S LAWS OF ELECTROMAGNETIC INDUCTION

Faraday gave two laws of electromagnetic induction.

First law : *Whenever there is change in the magnetic flux associated with a circuit, an e.m.f. is induced in the circuit. This is also known as* ***Neumann's law***

Second law : *The magnitude of the induced e.m.f. (e) is directly proportional to the time rate of change of the magnetic flux through the circuit.*

i.e., $e \propto \frac{\Delta\phi}{\Delta t}$ or, $e = k\frac{\Delta\phi}{\Delta t}$

In the limit, $\Delta t \to 0$, $e = \frac{d\phi}{dt}$

k = const. of proportionality depending upon the system of units used.

In the **S.I. system**, emf 'e' is measured in volt and $\frac{d\phi}{dt}$ in Wb/sec.

In MKS or SI system, these units are so chosen that k = 1, and 1 volt = 1 Wb/sec

Induced current or e.m.f. lasts only for the time for which the magnetic flux is changing.

If the coil has N turns, then the emf will be induced in each turn and the emf's of all the turns will be added up. If the turns of coil are very close to each other, the magnetic flux passing through each turn will be same.

So, *the induced emf in the whole coil* $e = N\frac{\Delta\phi}{\Delta t}$

$N\phi$ = number of 'flux linkages' in the coil.

LENZ'S LAW AND CONSERVATION OF ENERGY

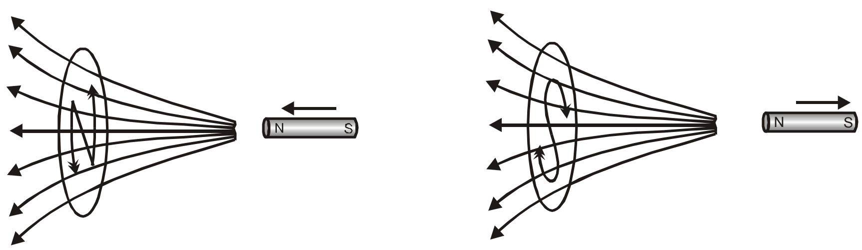
According to Lenz's law, *the direction of the induced current is such that it opposes the change in the magnetic flux that causes the induced current or e.m.f.* i.e., induced current tries to maintain flux.

On combining Lenz's law with Faraday's laws $e = -\frac{d\phi}{dt}$

–ve sign indicating that the induced e.m.f. opposes the change in the magnetic flux. The direction of the induced current or e.m.f. is given by Lenz's law. **The Lenz's law is consistent with the law of conservation of energy.**

The induced e.m.f. is produced at the cost of mechanical work done by an external agent. In the magnet and coil experiment when the N-pole of the magnet is moved towards the coil, the face of the coil facing the north pole acts like a north pole. (This can be found by Flemings' Right Hand Rule).

As the magnet is moved towards the coil, the magnetic flux linked with the coil increases.
To oppose this increase in flux, e.m.f. induced in the coil has to be in such a direction as to reduce the increase in flux.
The external agent has to do some work against this force of repulsion between the two N-poles.
Similarly, if the magnet with its N-pole is moved away from the coil, then the face of the coil acts like a South pole and hence the flux linked with the coil tends to decrease. The induced current or e.m.f. must now be in a direction so as to increase the flux as shown in figure.



(a) *Fig. 4.56* (b)

The external agent has to do work against this force of attraction between the N and S pole and this is converted into electrical energy. Suppose if on moving the N pole of the magnet towards the coil, a south polarity is induced on the face of the coil, then the magnet would be attracted to the coil, and there would be a continuous increase in magnetic flux linked with the coil leading to a continuous increase in e.m.f. without any expenditure of energy and this would violate the principle of conservation of energy.

Induced Current and Induced Charge

If in a coil of N turns the rate of change of magnetic flux be $\Delta\phi/\Delta t$, then the induced emf in the circuit is $e = -N\,(\Delta\phi/\Delta t)$.
If the coil be closed and the total resistance of its circuit be R, then the induced current in the circuit will be

$$I = \frac{e}{R} = \frac{N}{R}\frac{\Delta\phi}{\Delta t}.$$

It is clear from this equation that the induced current in the circuit depends upon the resistance, whereas the induced emf is independent of resistance.
The charge flowing through the circuit in time-interval Δt
$q = I \times \Delta t$

or $$q = \frac{N}{R}\frac{\Delta\phi}{\Delta t}\times\Delta t = \frac{N}{R}\Delta\phi$$

$$= \frac{\text{Number of turns} \times \text{change in magnetic flux}}{\text{Resistance}}$$

The induced charge does not depend upon the time-interval.
Whether the change in magnetic flux be rapid or slow, the charge in the circuit will remain the same.

Fleming's Right Hand Rule

Fleming's right hand rule gives the direction of the induced e.m.f. and current in a straight conductor moving perpendicular to the direction of magnetic field.

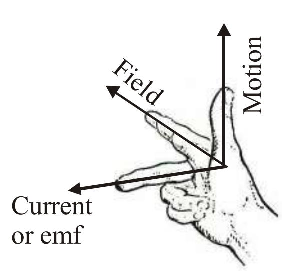


Fig. 4.57

Statement : Stretch out the thumb, fore finger and middle finger of the right hand mutually perpendicular to each other. If the fore finger points in the direction of magnetic field, the thumb in the direction of motion of the conductor, then the middle finger will point out the direction of induced current or induced e.m.f.

Determination of the Direction of the Induced Current in a Circuit (Using Lenz's Law)

The Lenz's law can be systematically applied as follows to determine the direction of induced current.

(1) Identify the loop in which the induced current is to be determined.

(2) Determine the direction of the magnetic field in this loop (i.e., in or out of the loop).

(3) The direction of flux is the same as the direction of the magnetic field. Determine if the flux through the loop is increasing or decreasing due to change in area, or change in magnetic field.

(4) Choose the appropriate current in the loop that will oppose the change in flux i.e.,

- **(i)** If the flux is into the paper and increasing, the flux due to the induced current should be out of the paper.
- **(ii)** If the flux is into the paper and decreasing, the flux due to the induced current should be into the paper.
- **(iii)** If the flux is out of the paper and increasing, the flux due to the induced current should be into the paper.
- **(iv)** If the flux is out of the paper and decreasing, the flux due to induced current should be out of the paper.

The above description is the physical interpretation of Lenz's law. We can determine the direction of the induced current mathematically by simply applying Lenz's law, $e_{ind} = -\dfrac{d\phi_B}{dt}$ with the appropriate sign conventions.

The **Right Hand Sign Convention :**

- Counter clockwise current/emf is +ve
- Clockwise current/emf is –ve
- Magnetic flux out of the paper is +ve
- Magnetic flux into the plane of the paper is –ve
- The rate of change of an increasing positive flux is +ve
- The rate of change of a decreasing positive flux is –ve
- The rate of change of an increasing negative flux is –ve
- The rate of change of a decreasing negative flux is +ve

SELF INDUCTION

The phenomenon of induction of e.m.f. in a coil due to change in current or magnetic flux linked with the coil is called self induction.

When a current I flows through a coil, the magnetic flux ϕ linked with the coil is $\phi = LI$, where **L is coefficient of self induction** or self inductance of the coil. On differentiating, we get

$$\frac{d\phi}{dt} = L\frac{dI}{dt} = -e$$

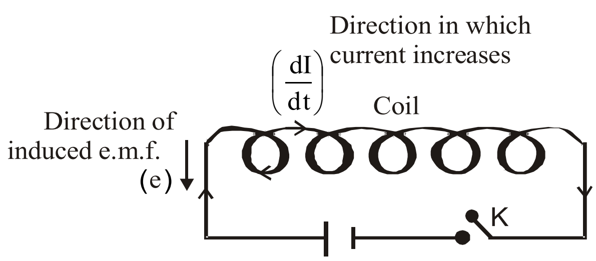


Fig. 4.58

If dI/dt = 1; L = – e.

Hence self inductance of a coil is equal to e.m.f. induced in the coil when rate of change of current through the same coil is unity. Coefficient of self induction of a coil is also defined as the magnetic flux linked with a coil when 1 ampere current flows through the same coil. The value of L depends on geometry of the coil and is given by $L = \dfrac{\mu_0 N^2 A}{\ell}$.

Where ℓ is length of the coil (solenoid), N is total number of turns of solenoid and A is area of cross section of the solenoid. The **S.I. unit** of L is henry. Coefficient of self induction of a coil is said to be one henry when a current change at the rate of 1 ampere/sec in the coil induces an e.m.f. of one volt in the coil.

Keep in memory

1. *Energy stored in a coil* = $\frac{1}{2}Li^2$ *where L is the self-inductance and i the current flowing through the inductor. The energy stored in the magnetic field of the coil.*
2. *The self inductance is a measure of the coil to oppose the flow of current through it. The role of self-inductance in an electrical circuit is the same as that of the inertia in mechanics. Therefore it is called electrical inertia.*
3. *The magnetic energy density (energy stored per unit volume) in a solenoid* $= \frac{B^2}{2\mu_0}$

- $E = \frac{1}{2}Li^2 = \frac{1}{2}(\mu_0 n^2 A\ell)\left(\frac{B}{\mu_0 n}\right)^2 = \left(\frac{B^2}{2\mu_0}\right)A\ell = \left(\frac{B^2}{2\mu_0}\right) \times \text{Volume}$

MUTUAL INDUCTION

The mutual induction is another kind of electromagnetic induction in which a changing current i_p in one circuit called the primary, induces an emf e_s and , in turn, may induce a current i_s in another nearby circuit, called the secondary S. Out of the two circuits involved in the mutual induction process, any one can be taken as primary, or secondary. However, the two circuits constitute a mutual inductor.

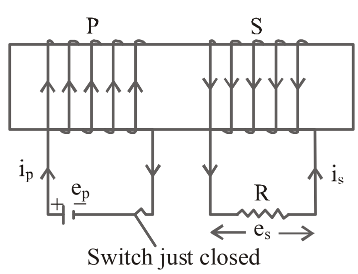


Fig. 4.59

When a constant, or variable current i flows through the primary P, then the total magnetic flux through each turn of the secondary S is Φ_{ms} and the total magnetic flux, or flux linkage, through all the N_s turns, assumed identical, of secondary S is

$$N_s \Phi_{ms} \propto i_p = Mi_p \qquad \Rightarrow \qquad M = \frac{N_s \phi_{ms}}{i_p}$$

where the constant of proportionatity M is a positive physical parameter, called the **mutual inductance**, or **coefficient of mutual induction**, of the two circuits.

Evidently, M is total magnetic flux, or flux linkage, through the secondary per unit current in the primary.

If the primary current i_p is variable, the induced emf in the secondary S is given by

$$e_s = -\frac{d}{dt}(Ns\,\phi_{ms}) = -\frac{d}{dt}(M\,i_p) = -M\frac{d\,i_p}{dt} \quad \text{or,} \quad M = -\frac{e_s}{\left(\frac{di_p}{dt}\right)}$$

which means that the mutual inductance M is the induced emf in the secondary per unit rate of change of current in the primary. The mutual inductance M depends on the geometry of two circuits and their proximity. It's SI unit is the same as that of the self inductance L, i.e., henry (H).

ELECTRIC GENERATOR

The large generators present in hydroelectric power plants depend on magnets for their operation. They convert the kinetic energy in moving water into electricity. Generators in fossil-fueled and nuclear-fueled power plants harness the kinetic energy in moving steam in the same way.

Electrical current can be generated by moving a metal wire through a magnetic field. This applies both to alternating current (AC) and direct current (DC) electricity.

Principle : When a coil of conducting wire is rotated in a magnetic field, electromagnetic induction results in an induced current flowing through the loop. In this way, mechanical energy is converted to electrical energy.
The device is called a generator or dynamo.
The generator will produce an electromotive force that will vary sinusoidally with the angle made by the coil and the applied field. Thus the direction of the current will vary and the current so produced is called an alternating current. A better name for the device is alternator.
Electric motor is analogous to an electric motor: the motor converts electrical energy into mechanical energy, while the alternator converts mechanical energy into electrical energy. The alternator does not create electricity out of nothing.
Working of generator : An electric generator, consists of a rotating rectangular coil ABCD placed between the two poles of a permanent magnet. The two ends of this coil are connected to the two rings R_1 and R_2. The inner side of these rings are made insulated. The two conducting stationary brushes B_1 and B_2 are kept pressed separately on the rings R_1 and R_2, respectively. The two rings R_1 and R_2 are internally attached to an axle. The axle may be mechanically rotated from outside to rotate the coil inside the magnetic field.
Outer ends of the two brushes are connected to the galvanometer to show the flow of current in the given external circuit. When the axle attached to the two rings is rotated such that the arm AB moves up (and the arm CD moves down) in the magnetic field produced by the permanent magnet. Let us say the coil ABCD is rotated clockwise in the arrangement. By applying Fleming's right-hand rule, the induced currents are set up in these arms along the directions AB and CD. Thus an induced current flows in the direction ABCD. If there are larger numbers of turns in the coil, the current generated in each turn adds up to give a large current through the coil. This means that the current in the external circuit flows from B_2 to B_1.

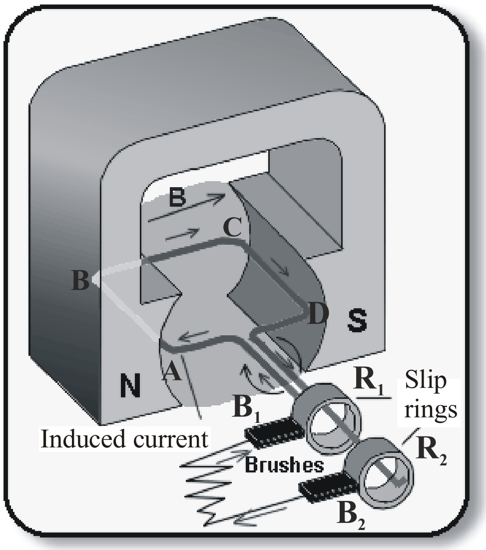


Fig. 4.60 : AC generator

After half a rotation, arm CD starts moving up and AB moving down. As a result, the directions of the induced currents in both the arms change, giving rise to the net induced current in the direction DCBA.
The current in the external circuit now flows from B_1 to B_2. Thus after every half rotation the polarity of the current in the respective arms changes. Such a current, which changes direction after equal intervals of time, is called an alternating current (abbreviated as AC). This device is called an AC generator.
To get a direct current (DC, which does not change its direction with time), a split-ring type commutator must be used. With this arrangement, one brush is at all times in contact with the arm moving up in the field, while the other is in contact with the arm moving down.

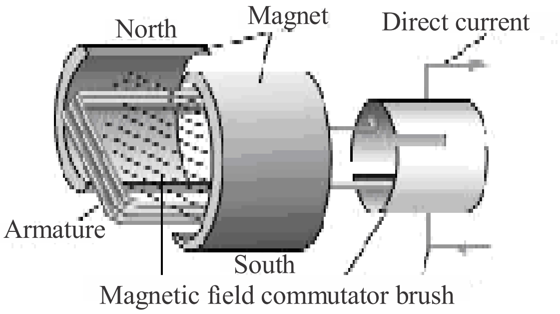


Fig. 4.61 : Split-ring type commutator.

The difference between the direct and alternating currents is that the direct current always flows in one direction, whereas the alternating current reverses its direction periodically. Most power stations constructed these days produce AC. In India, the AC changes direction after every 1/100 second, that is, the frequency of AC is 50 Hz. An important advantage of AC over DC is that electric power can be transmitted over long distances without much loss of energy.

CONNECTING TOPIC

TERRESTERIAL MAGNETISM

William Gilbert suggested that earth itself behaves like a huge magnet. This magnet is so oriented that its S pole is towards geographic north and N pole is towards the geographic south.

The earth behaves as a magnetic dipole inclined at small angle 11.5° to the earth's axis of rotation with its south pole pointing geographic north.

The idea of earth having magnetism is supported by following facts.

(i) A freely suspended magnet always comes to rest in N-S direction.

(ii) A piece of soft iron buried in N-S direction inside the earth acquires magnetism.

(iii) Existence of neutral points.

When we draw field lines of bar magnet we get neutral points where magnetic field due to magnet is neutralized by earth's magnetic field.

The magnetic field at the surface of earth ranges from nearly 30 μT near equator to about 60 μT near the poles. The magnetic field on the axis is nearly twice the magnetic field on the equatorial line.

Cause of earth's magnetism

Sir William Gilbert first suggested the existence of a powerful magnet inside the earth. This is not possible because

(a) temperature inside earth is so high that it will not be possible for magnet to retain magnetism.

(b) if there was a magnet inside the earth then position of earth's magnetic poles would have not changed.

(c) the process of magnetisation of this magnet is not understood.

Grover suggested that earth's magnetism is due to flow of current near outer surface of earth. These currents are produced due to sun. The hot air rising from regions near equator while going towards north and south hemispheres gets electrifield. These then magnetise ferromagnetic materials near the surface of earth.

According to another view earth's core has many conducting materials like iron and nickel in molten state. Conventional currents are produced in this semi fluid core due to rotation of earth about its axis which generates magnetism.

Another view says magnetism is due to presence of ionised gases in atmosphere. The high energy sun rays ionize gas atoms in upper layer of atmosphere. The radioactivity of atmosphere and cosmic rays also ionize the gases. Strong electric currents flow due to rotation of earth producing magnetism.

Thus most likely cause of earth's magnetism is the motion and distribution of charged materials in and outside the earth.

Some Definitions

Geographic Axis : It is straight line passing through the geographic poles of the earth. It is the axis of rotation of the earth. It is known as polar axis

.

Geographic Meridian : It is a vertical plane passing through geographic north and south poles of the earth.

Geographic Equator : A great circle on the surface of the earth in a plane perpendicular to geographical axis is called geographic equator. All places on geographic equator are at equal distances from geographical poles.

Magnetic Axis : It is a straight line passing through the magnetic poles of the earth. It is inclined to geographic axis at nearly 11.5°.

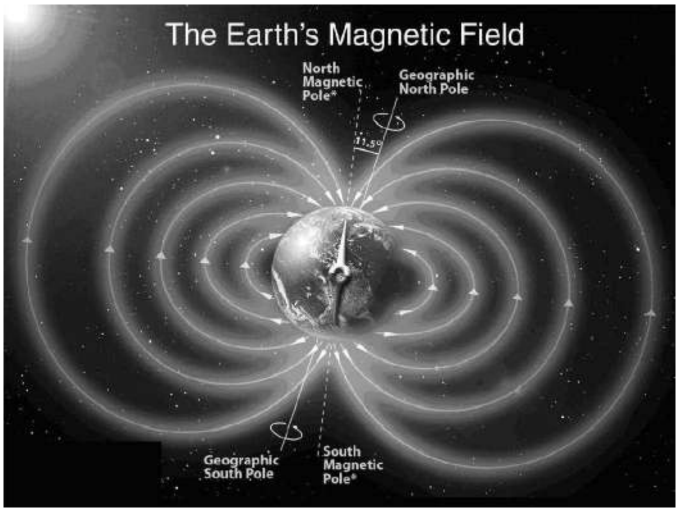


Fig. 4.62

Magnetic Meridian : It is a vertical plane passing through the magnetic north and south poles of the earth.

Magnetic Equator : A great circle on the surface of the earth in a plane perpendicular to magnetic axis is called magnetic equator. All places on magnetic equator are at equal distance from magnetic poles.

COMPONENTS OF EARTH'S MAGNETIC FIELD

The resultant magnetic field $\vec{B}$ of earth at a place has the two components, namely, the vertical component B_V and horizontal component B_H. The component B_V has the vertical direction which is downwards in the northern hemisphere and upwards in the southern hemisphere. The component B_H has the horizontal direction which is from the south to the north everywhere.

Vertical component of earth's magnetic field, $B_V = B \sin\theta$

Horizontal component of earth's magnetic field, $B_H = B\cos\theta$

Resultant magnetic field $B = \sqrt{\left(B_V^2 + B_H^2\right)}$

$$\frac{B\sin\theta}{B\cos\theta} = \tan\theta = \frac{B_V}{B_H}$$

The vertical component $B_V = 0$ at the magnetic equator and the horizontal component $B_H = 0$ at the magnetic north and south poles of earth. At Delhi, $B_H = 35\ \mu T = 0.35 G$.

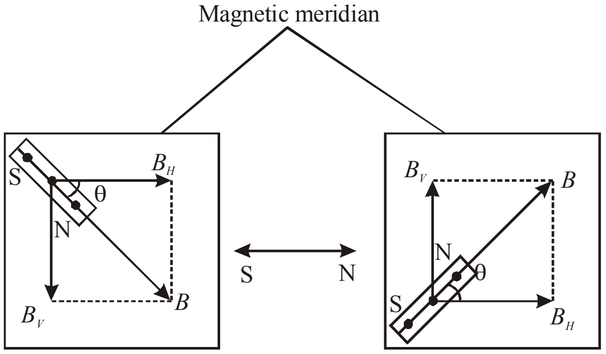


Fig. 4.63

Angle of Dip or Inclination, θ

At a place, the angle θ which the resultant magnetic field $\vec{B}$ of earth makes with the horizontal is called the angle of dip, or inclination. A freely-suspended magnet will keep it's axis at this angle θ with the horizontal, the south pole being above the north pole in the northern hemisphere and the south pole being below the north pole in the southern hemisphere. It is 0º at the magnetic equator and 90º at the magnetic north and south poles of earth. At other places, it lies between 0º and 90º. At Delhi, it is 42º 12.7′. The angle of dip θ measured in the magnetic meridian is called the true angle of dip and the angle of dip θ′ measured in any other vertical plane inclined at an angle ϕ with the magnetic meridian is called the apparent angle of dip. The 'Dip circle' is used to measure the angle of dip in any vertical plane.

$$\tan\theta = \frac{B_V}{B_H},$$

$$\tan\theta' = \frac{B_V}{B_H'} = \frac{B_V}{B_H\cos\phi}$$

$$\Rightarrow \quad \tan\theta' = \left(\frac{1}{\cos\phi}\right)\tan\theta$$

$$\Rightarrow \quad \theta' > \theta$$

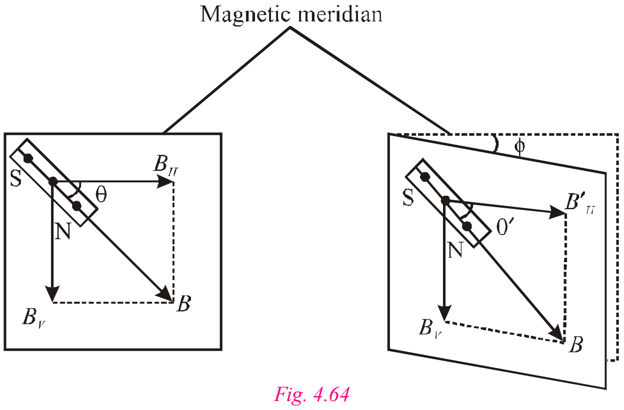


Fig. 4.64

Angle of Declination, α

At a place, the angle between the magnetic and geographic meridians is called the angle of declination. It is 0º at Delhi.

Magnetic Elements of Earth

The three parameters, namely, the angle of dip or inclination θ, variation or declination α and horizontal component B_H of earth's magnetic field $\vec{B}$, are together called the magnetic elements of earth. These elements completely define the earth's magnetism.

Magnetic Compass:

Present day magnetic compasses use the same forces that guided ancient mariners. A magnetized needle, in conjunction with a compass card, rotates horizontally. Present day compasses are superior to the ancient ones through a heightened knowledge of magnetic laws and greater precision in construction.

The Earth's magnetic lines of force provide the directional information needed to navigate. A compass detects and converts the energy from these magnetic lines of force into a directional display. In order to understand the operation of a ship's compass, it is first necessary to understand some basic information about the Earth's magnetic field.

Fig. 4.65

Magnetism in medicine

An electric current always produces a magnetic field. Even weak ion currents that travel along the nerve cells in our body produce magnetic fields. When we touch something, our nerves carry an electric impulse to the muscles we need to use. This impulse produces a temporary magnetic field. These fields are very weak and are about one-billionth of the earth's magnetic field. Two main organs in the human body where the magnetic field produced is significant, are the heart and the brain. The magnetic field inside the body forms the basis of obtaining the images of different body parts. This is done using a technique called Magnetic Resonance Imaging (MRI). Analysis of these images helps in medical diagnosis. Magnetism has, thus, got important uses in medicine.

Fact: In research and industry, MRI is known as NMR – Nuclear Magnetic Resonance. It's more or less the same process, but the medical establishment prefers the term MRI because some patients are scared off by the word nuclear.
The first MRI on a human was made in July 1977 by Dr. Raymond Damadian of New York. MRI patients are sometimes injected with gadolinium, a contrast agent that can make abnormalities such as tumors clearer due to the element's special magnetic properties.

MRIs are most commonly used for cancer patients (about 35 percent of all scans) and patients with spinal problems (about 30%).

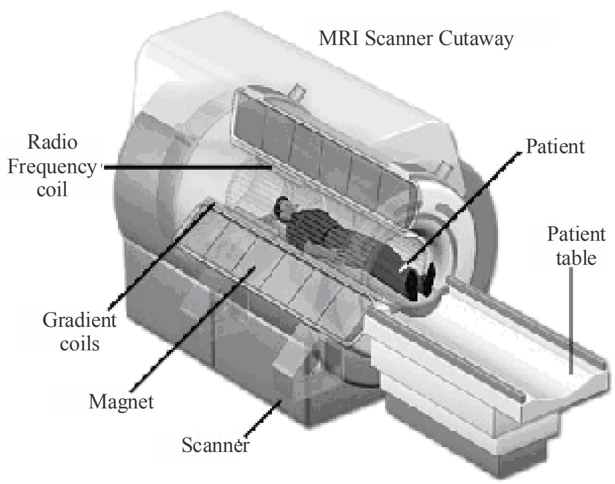


Fig. 4.66

NEUTRAL POINTS

Points where net magnetic field is zero are called neutral points.

Magnet in Horizontal Position

When a magnet is placed in the horizontal position with it north pole facing the north, we get the two neutral points P_1 and P_2 on the equator of magnet, symmetrically placed with respect to the magnet, as shown. At the neutral points, the earth's horizontal component $\vec{B}_H$ and the magnetic field $\vec{B}$ of magnet balance each other so that the resultant magnetic field is zero there. Therefore,

$$B_H = B = \left(\frac{\mu}{4\pi}\right)\frac{M}{(r^2+l^2)^{3/2}}$$

$$\approx \left(\frac{\mu}{4\pi}\right)\frac{M}{r^3} \text{ for } l << r$$

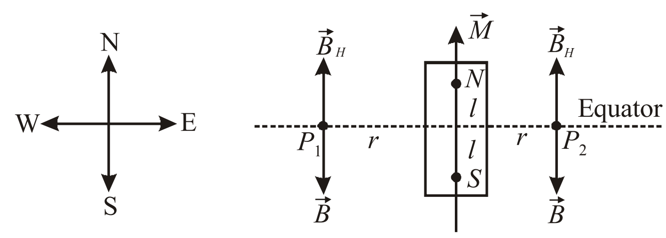


Fig. 4.67

When the magnet is placed in the horizontal position with it's north pole facing the south, we get the two neutral points P_1 and P_2 on the axis of magnet, symmetrically placed with respect to the magnet, as shown. At the neutral points, we have

$$B_H = B = \left(\frac{\mu}{4\pi}\right)\frac{2Mr}{(r^2 - l^2)^2}$$

$$\approx \left(\frac{\mu}{4\pi}\right)\frac{2M}{r^3} \text{ for } l << r$$

Magnet in Vertical Position

When the magnet is placed in the vertical position with it's north pole resting on the table, we get only one neutral point P on the south of magnet in the plane of the table top, as shown. At the neutral point we have

$$B_H = B = B_N - B_S\cos\theta \quad \text{(for short magnet)}$$

$$\approx B_N \quad \text{(for long magnet, i.e., } l >> r\text{)}$$

where,

$$B_N = \left(\frac{\mu}{4\pi}\right)\frac{m}{r^2}$$

$$B_S = \left(\frac{\mu}{4\pi}\right)\frac{m}{(r^2 + 4l^2)}$$

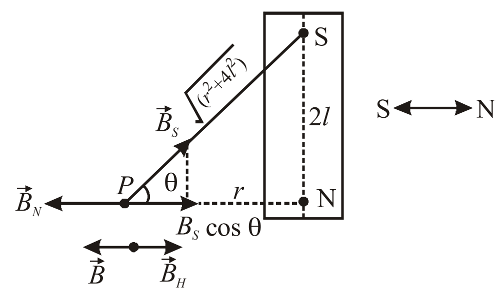


Fig. 4.68

are the magnetic fields due to the two poles, taken separately.

When the magnet is placed in the vertical position with it's south pole resting on the table, we get only one neutral point P on the north of magnet in the plane of the table top, as shown. At the neutral point, we have

$$B_H = B = B_S - B_N\cos\theta \text{ (for short magnet)}$$

$$\cong B_S \text{ (for long magnet, i.e., } l >> r\text{)}$$

where $$B_N = \left(\frac{\mu}{4\pi}\right)\frac{m}{(r^2 + 4l^2)}$$

and $$B_S = \left(\frac{\mu}{4\pi}\right)\frac{m}{r^2}$$

are the magnetic fields due to the two poles.

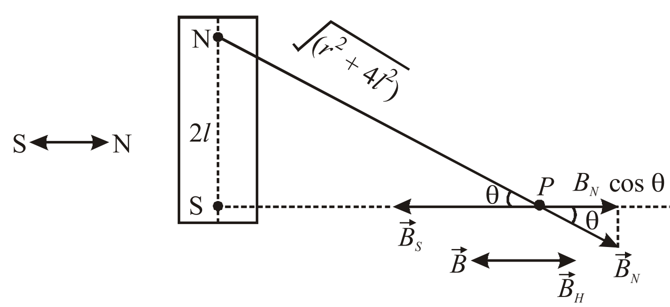


Fig. 4.69

CHECK Point

Magnet A has twice the magnetic field strength of magnet *B*, and, at a certain distance, it pulls on magnet *B* with a force of 50 N. With how much force, then, does magnet *B* pull on magnet *A* ?

SOLUTION

The magnet B will pull on magnet A with the same force as magnet A pulls on magnet B, i.e, with a force of 50 N only because the force of attraction between the two magnets is a combined property of both the magnets and acts equally on both.

MAGNETIC MATERIALS

Certain materials, when placed in a magnetic field $\vec{B}_0$, i.e., in a magnetising field intensity $\vec{H} = \vec{B}_0/\mu_0$, get magnetised. Such materials are called the magnetic materials. Some materials get magnetised very strongly, e.g., ferromagnetics and others get magnetised very feebly, e.g., diamagnetics and paramagnetics.

Terms Related to Magnetism

Magnetic intensity $(\vec{H})$: When a magnetic material is placed in a magnetic field, it becomes magnetised. The capability of the magnetic field to magnetise a material is expressed by means of a magnetic vector $\vec{H}$, called the `magnetic intensity' of the field.

The relation between magnetic induction B and magnetising field $\vec{H}$ is $\vec{B} = \mu\vec{H}$, μ being permeability of medium.

Intensity of magnetisation (I_m) : When a material is placed in a magnetising field, it acquires magnetic moment M. The intensity of magnetisation is defined as the magnetic moment per unit volume i.e., $I_m = \frac{M}{V}$, V being volume of mateiral.

If the material is in the form of a bar of cross-sectional area A, length $2l$ and pole strength m, then

$$M = m \times 2\ell; V = A \times 2\ell \qquad \therefore \; I_m = \frac{M}{V} = \frac{m.2\ell}{A.2\ell} = \frac{m}{A}$$

Magnetic susceptibility (χ) : The magnetic susceptibility is defined as the intensity of magnetisation per unit magentising field

i.e., $\chi = \frac{I_m}{H}$.

Magnetic permeability (μ) : The magnetic permeability of a material is the measure of degree to which the material can be permeated by a magnetic field and is defined as the ratio of magnetic induction (B) in the material to the magnetising field

i.e., $\mu = \frac{B}{H}$

Relation Between Magnetic Susceptibility and Permeability

We have magnetic induction in mateiral, $B = \mu H$

Also $B = B_0 + B_m$

where B_0 = magnetic induction in vacuum produced by magnetising field

B_m = magnetic induction due to magnetisation of material.

But $B_0 = \mu_0 H$ and $B_m = \mu_0 I_m \Rightarrow B = \mu_0[H + I_m]$

$\therefore \; B = \mu_0 H \left[1 + \frac{I_m}{H}\right] = B_0\,[1+\chi]$; $\therefore \; B/B_0 = [1+\chi]$ $\therefore \; B/B_0 = \frac{\mu H}{\mu_0 H} = \mu/\mu_0$, the relative magnetic permeability

$\therefore \; \mu_r = 1 + \chi$ This is required relation.

CLASSIFICATION OF MAGNETIC MATERIALS

According to the behaviour of substances in magnetic field, they are classified into three categories

(I) Diamagnetic Substances: These are substances which when placed in a strong magnetic field acquire a feeble magnetism opposite to the direction of magnetising field.

The examples are copper, gold, antimony, bismuth, alcohol, water, quartz, hydrogen, etc.

The characteristics of diamagnetic substances are:

(a) They are feebly repelled by a strong magnet

(b) Their susceptibility is negative (i.e. $\chi < 0$)

(c) Their relative permeability is less than 1 (i.e. $\mu_r < 1$)

(d) Their susceptibility is independent of magnetising field and temperature (except for Bismuth at low temperature)

(II) Paramagnetic Substances: These are the materials which when placed in a strong magnetic field acquire a feeble magnetism in the same sense as the applied magnetic field. The examples are platinum, aluminium, chromium, manganese, $CuSO_4$, O_2, air, etc.

The characteristics of paramagnetic substances are:

(a) They are attracted by a strong magnet

(b) Their susceptibility is positive but very small ($\chi > 0$)

(c) Their relative permeability is slightly greater than unity. ($\mu > 1$)

(d) Their susceptibility and permeability do not change with the variation of magnetising field.

(e) Their susceptibility is inversely proportional to temperature, $\left(\text{i.e. } \chi \propto \frac{1}{T}\right)$

(f) Found in those material which have atoms containing odd number of electrons

(III) Ferromagnetic Substances: These are the substances which are strongly magnetised by relatively weak magnetising field in the same sense as the magnetising field. The examples are Ni, Co, iron and their alloys.

The characteristics of ferromagnetic substances are :

(a) They are attracted even by a weak magnet.

(b) The susceptibility is very large and positive. ($\chi >> 0$)

(c) The relative permeability is very high (of the order of hundreds and thousands). ($\mu >> 1$)

(d) The intensity of magnetisation is proportional to the magnetising field H for smaller values, varies rapidly for moderate values and attains a constant value for larger values of H.

(e) The susceptibility of a ferromagnetic substance is inversely proportional to temperature

i.e., $\chi \propto 1/T \Rightarrow \chi = \frac{C}{T}$; C = curie constant.

This is called **Curie law**. At a temperature called **curie temperature**, ferromagnetic substance becomes paramagnetic. The curie temperatures for Ni, Fe and Co are 360ºC, 740ºC and 1100ºC respectively.

(f) Found in those material which have domains and can be converted into strong magnets

HYSTERESIS

When a bar of ferromagnetic material is magnetised by a varying magnetic field and the intensity of magnetisation I_m induced is measured for different values of magnetising field H, the graph of I versus H is as shown in fig.

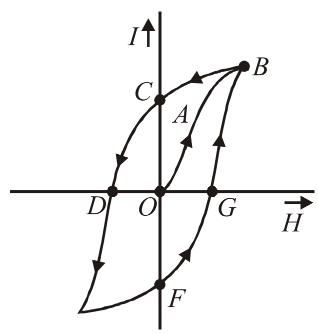


Fig. 4.70

The graph shows

(i) When magnetising field is increased from O the intensity of magnetisation I_m increases and becomes maximum (i.e. point A). This maximum value is called the **saturation value**.

(ii) When H is reduced, I_m reduces but is not zero when H = 0. The remainder value OB of magnetisation when H = 0 is called the residual magnetism or **retentivity**. OB is retentivity.

(iii) When magnetic field H is reversed, the magnetisaiton decreases and for a particular value of H, it becomes zero i.e., for H = OC, I = 0. This value of H is called the **coercivity**.

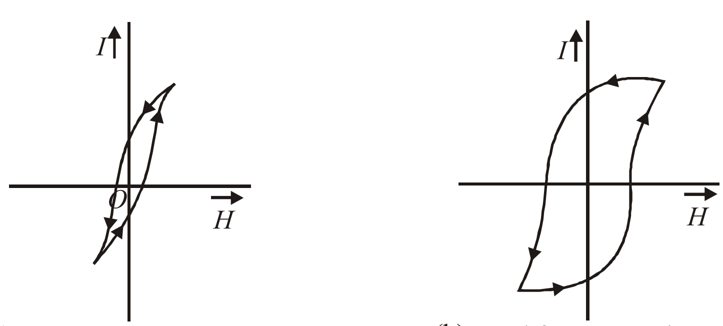
(iv) When field H is further increased in reverse direction, the intensity of magnetisation attains saturation value in reverse direction (i.e., point D).

(v) When H is decreased to zero and changed direction in steps, we get the part DFGA.

Properties of Soft Iron and Steel

For soft iron, the susceptibility, permeability and retentivity are greater while coercivity and hysteresis loss per cycle are smaller than those of steel.

Permanent magnets are made of steel and cobalt while electromagnets are made of soft iron.

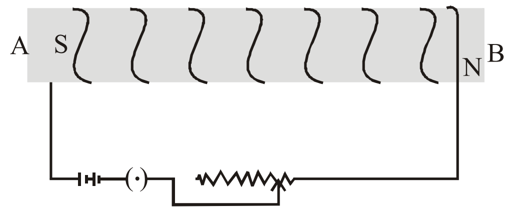


(a) Soft ferromagnetics (b) Hard ferromagnetics

Fig. 4.70

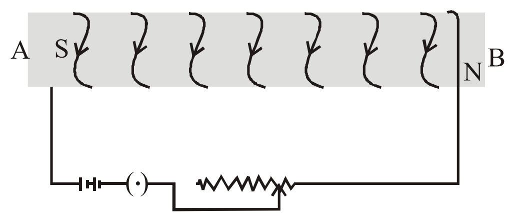
MISCELLANEOUS SOLVED EXAMPLES

1. (a) Fig. below shows a solenoid. Copy the diagram and mark on it :
   (i) The direction of flow of current.
   (ii) The magnetic polarity at ends A and B.



   (b) Suggest three ways of increasing, strength of the magnetic field of a solenoid.

Sol. (a) The complete diagram is shown in Fig.



   (i) Current flows from end A of the solenoid to end B in the clockwise direction.
   (ii) As current at the end A is in clockwise direction, it develops south pole; and the current at end B is in anticlockwise direction, it develops a north pole.

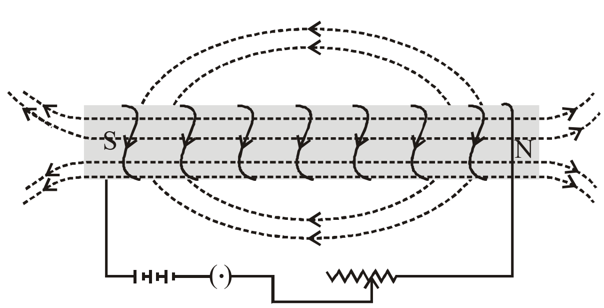
(b) The strength of the magnetic field can be increased by:
   (i) increasing the current.
   (ii) increasing number of turns of wire.
   (iii) inserting a soft iron core along the axis of the solenoid.

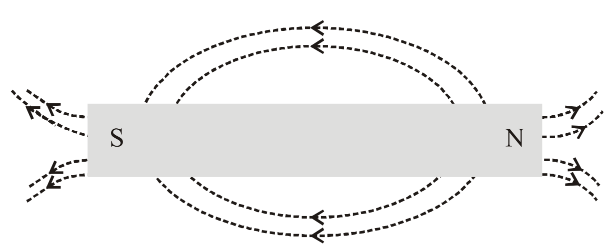
2. Why is soft iron generally used as the core of the electromagnet?

Sol. (a) Soft iron has less retenitvity. So it acquires the magnetic properties only when the current flows through the coil wound on it and loses the magnetic properties as the current is switched off.
(b) The soft iron intensifies the magnetic field of the electromagnet because of its high permeability.

3. Draw the magnetic lines of force in case of:
(a) a solenoid and **(b) a bar magnet.**

Sol. (a) Magnetic lines of force in case of a solenoid. (b) Magnetic lines of force in case of a bar magnet.





The magnetic field of a solenoid is very similar to that of a bar magnet. Only difference is that the magnetic lines of force are parallel to each other inside the solenoid.

4. State two dissimilarities between a d.c. motor and an a.c. generator.

Sol. (i) A d.c. motor converts electrical energy to mechnical energy, whereas an a.c. generator converts mechanical energy to electrical energy.
(ii) A d.c. motor uses a split ring commutator, whereas an a.c. generator uses a pair of slip rings.

SOLVED EXAMPLES BASED ON CONNECTING TOPICS

5. A horizontal straight wire 5 cm long weighing 1.2 g^{-1} is placed perpendicular to a uniform horizontal magnetic field of the flux density 0.6T. If the resistance of the wire is $3.8\ \Omega\ m^{-1}$ calculate the potential difference that has to be applied between the ends of the wire to make it just supporting ($g = 9.8\ ms^{-1}$)

Sol. Here, $l = 5cm = 5\times10^{-2}m$

Mass of the wire, m = mass per unit length × length of the wire.

$= 1.2\times10^{-3}\ kg\ m^{-1}\times5\times10^{-2}m = 6\times10^{-5}\ Kg,$

$B = 0.6T$

Resistance of the wire R = (Resistance per unit length x length of the wire)

$= 3.8\times5\times10^{-2} = 0\ 19\ \Omega$

Let V be the P.d. applied between the ends of the wire, for the wire to be self supporting:

$$mg = BI\,l = B\frac{V}{R}l$$

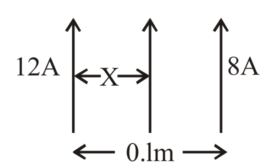
$$\therefore\quad V = \frac{mg\times R}{B\ell} = \frac{6\times10^{-5}\times9.8\times0.19}{0.6\times5\times10^{-2}} = 3.72\times10^{-3}V$$

6. Two long parallel conductors carry respectively currents of 12 and 8A in the same direction. If the wires are 10 cm apart, find where the third parallel wire also carrying a current must be placed so that the force experienced by it shall be zero.

Sol. For the force on the third conductor to be zero, the direction of the flux density due to the current flowing in the two wires must be opposite in the position of the wire.

$\therefore$ The third wire must be placed between the wire. Let the third wire placed at a distance *x m* from the wire carrying 12A, then, $B_1 = B_2$

$$\frac{\mu_o I_1}{2\pi x} = \frac{\mu_o I_2}{2\pi(0.1-x)}$$



or $\frac{12}{x} = \frac{8}{0.1-x}$ or $\frac{3}{x} = \frac{2}{0.1-x}$

or $0.3 = 5x$ or, $x = \frac{0.3}{5} = 0.06\ m$

7. A narrow vertical rectangular coil is suspended from the middle of its upper side with its plane parallel to a uniform horizontal magnetic field of 0.02 T. The coil has 10 turns and the lengths of its vertical and horizontal sides are 0.1 m and 0.05 m respectively. Calculate the torque on the coil when a current of 5A is passed into it. What would be the new value of the torque if the plane of the vertical coil was initially at 60° to the magnetic field and a current of 5A was passed into the coil.

Sol. Given: B = 0.02 T, N = 10 turns

$A = 1\times b = 0.1\times0.05 = 0.005\ m^2 : I = 5A$

Torque = BINA = $0.02\times5\times10\times0.005 = 0.005\ Nm = 5\times10^{-3}Nm$

New value of the torque when the plane of the vertical coil was at 60° to the magnetic field

$= BINA\cos\theta = 5\times10^{-3}\cos60^o$

$= 5\times10^{-3}\times\frac{1}{2} = 2.5\times10^{-3}\ Nm.$

8. Find the self inductance of a coil in which an e.m.f. of 10 V is induced when the current in the circuit changes uniformly from 1 A to 0.5 A in 0.2 sec.

Sol. Given : e = 10 V and $\frac{dI}{dt} = \frac{1-0.5}{0.2} = \frac{0.5}{0.2} = 2.5\ A/s$

Self inductance of coil $L = \frac{e}{dI/dt} = \frac{10}{2.5} = 4\ H$ $\quad\because\ e = L\frac{dI}{dt}$ (Considering magnitude only)

9. A conductor of length 10 cm is moved parallel to itself with a speed of 10 m/s at right angles to a uniform magnetic induction 10^{-4} Wb/m². What is the induced e.m.f. in it?

Sol. Given : $\ell = 10\ cm = 0.1\ m$, v = 10 m/s

$B = 10^{-4}\ Wb/m^2$

e.m.f. induced in conductor $e = B\,\ell\,V = 10^{-4}\times0.1\times10 = 10^{-4}\ V$

1 EXERCISE

Fill in the Blanks :

DIRECTIONS : *Complete the following statements with an appropriate word / term to be filled in the blank space(s).*

1. A compass needle is a .... magnet.
2. Field lines are used to represent a ....
3. Field lines are shown closer together where the magnetic field is ....
4. A metallic wire carrying an electric current has associated with it a .... field.
5. The field lines about the wire consist of a series of concentric circles whose direction is given by the .... rule.
6. The magnetic lines of force are the lines drawn in a magnetic field along which a .... pole would move.
7. An electric current can be used for making temporary magnets known as ....
8. The unit of magnetic field is ....
9. The S.I. unit of magnetic flux ....
10. The force between currents is called the .... force.
11. The N-pole of a compass points to the .... pole of a permanent magnet.
12. The force that a magnetic field exerts on a current is always perpendicular to the .... and to the ....
13. In a magnetic field pointing away from you, an electron traveling to the right will experience a force in the .... direction.
14. Magnetic fields are produced by ....
15. You are looking into a solenoid, at its S-pole, along its axis. From your view point, the direction of the current in the solenoid is ....
16. Crowding the wires of a solenoid more closely together will .... the strength of the field inside it.
17. A paramagnet magnet behaves like a solenoid because both contain currents in the form of ....
18. Magnetic field lines emerge from the .... pole of a solenoid or a permanent magnet.
19. You are looking down the axis of a solenoid, and the current from your position is clockwise. The end of the solenoid facing you is a .... pole.
20. A generator converts mechanical energy into .... energy. It works on the basis of ....
21. In our houses we receive AC electric power of .... with a frequency of ....
22. The frequency for A.C. (alternating current) in USA is ....
23. The armature in a motor rotates within a(n) .... field.
24. To produce DC, the output of a generator must be fed through a (n) ....
25. In any generator, the current in the armature is of the .... type.
26. The phenomenon of production of back e.m.f. in a coil due to flow of varying current through it is called..............
27. The unit of self-inductance in SI system is ....
28. An e.m.f. is induced in a coil when .... linked with it changes.
29. In an AC generator, maximum number of lines of force pass through the coil when the angle between the plane of coil and lines of force is ....

True / False :

DIRECTIONS : *Read the following statements and write your answer as true or false.*

1. Energy associated with an electric field is analogous to potential energy whereas the energy associated with the magnetic field is analogous to kinetic energy.
2. No net force acts on a rectangular coil carrying a steady current when suspended freely in a uniform magnetic field.
3. An electron and a proton move in a uniform magnetic field with same speed perpendicular to the magnetic field. They experience forces in opposite directions differing by a factor of 1840.
4. A positive charge projected along the axis of a current carrying solenoid moves undeviated from its original path.
5. There is no change in the energy of a charged particle moving in a magnetic field although a magnetic force is acting on it.
6. An electron does not suffer any deflections while passing through a region. This makes sure that there is no magnetic field in that region.
7. The field at the centre of a long circular coil carrying current will be parallel straight lines.
8. A magnetic field exists in the region surrounding a magnet, in which the force of the magnet can be detected.
9. The pattern of the magnetic field around a conductor due to an electric current flowing through it depends on the shape of the conductor.
10. A current-carrying conductor when placed in a magnetic field always experiences a force.
11. The direction of force on a current carrying conductor placed in a magnetic field can be reversed by reversing the direction of current flowing in the conductor.
12. The direction of force on a current carrying conductor placed in a magnetic field cannot be reversed by reversing the direction of magnetic field.
13. Two magnetic lines of force never intersect each other.
14. The field lines inside the infinite solenoid are in the form of parallel straight lines.
15. An electric generator works on the principle of electromagnetic induction.
16. In a DC electric motor a pair of split rings is used as commutator.

17. The induced e.m.f. depends only the turns of the coil
18. The magnitude of induced current can be increased by decreasing the speed of rotation of coil.
19. The magnitude of induced current can be decreased by increasing the area of cross section of coil.

Match the Following :

DIRECTIONS : *Each question contains statements given in two columns which have to be matched. Statements (A, B, C, D) in column I have to be matched with statements (p, q, r, s) in column II.*

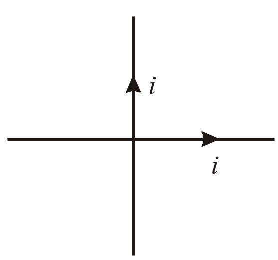
1.

Column I	Column II
(A) An electric motor works on	(p) to a battery
(B) An electric motor is also	(q) direct current
(C) A commutator is used to	(r) reverse the direction of flow of current.
(D) Commutator rings are connected	(s) known as DC MOTOR

2. Column II gives approximate values of magnetic fields due to source given in column I

Column I	Column II
(A) At surface of neutron star	(p) 10^{-10} T
(B) Near big electromagnet	(q) 1.5 T
(C) At earth surface	(r) 10^{8} T
(D) In interstellar space	(s) 10^{-4} T

3. Equal currents i flow in two wires along x and y axis as shown. Match the following :

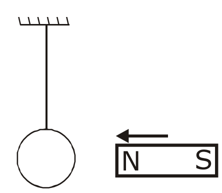


Column I	Column II
(A) Magnetic field in first quadrant	(p) inwards
(B) Magnetic field in second quadrant	(q) outwards
(C) Magnetic field in third quadrant	(r) may be inwards or outwards
(D) Magnetic field in fourth quadrant	

Very Short Answer Questions:

DIRECTIONS : *Give answer in one word or one sentence.*

1. Why does a compass needle get deflected when brought near a bar magnet?
2. A current through a horizontal power line flows in east to west direction. What is the direction of magnetic field at a point directly below it and at a point directly above it ?
3. Why don't two magnetic lines of force intersect each other?
4. Consider a circular loop of wire lying in the plane of the table. Let the current pass through the loop clockwise. Apply the right-hand rule to find out the direction of the magnetic field inside and outside the loop.
5. List three sources of magnetic fields.
6. When is the force experienced by a current–carrying conductor placed in a magnetic field largest?
7. What do you conclude from Oersted's experiment?
8. Name the types of electromagnets commonly used.
9. When can an electric charge give rise to a magnetic field?
10. Why is soft iron used as the core of the electromagnet used in electric bell ?
11. How will the direction of force be changed, if the current is reversed in the conductor placed in a magnetic field?
12. Describe a set up for plotting the magnetic lines of force in a straight conductor.
13. What is the direction of magnetic field at the centre of a coil carrying current in (i) clockwise (ii) anticlockwise direction?
14. Why does a current carrying, freely suspended solenoid rest along a particular direction ?
15. What constitutes the field of a magnet?
16. Name the physical quantity whose S.I. unit is Wb - m^2. Is it a scalar quantity or vector quantity?
17. Name the rule used to find the direction of force on a current carrying conductor.
18. State Fleming's right hand rule.
19. Does the A.C. generator have any slip ring ?
20. An alternating electric current has a frequency of 50 Hz. How many times does it change its direction in one second?
21. What will be the frequency of an alternating current if its direction changes after every 0.01 s?
22. Give the direction of induced current in the wire loop, when the magnet moves forward as shown in the figure.



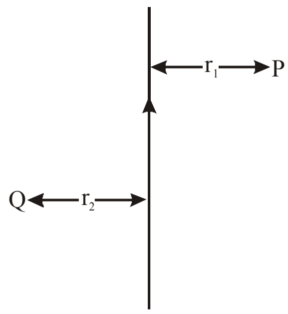
Short Answer Questions :

DIRECTIONS : *Give answer in 2-3 sentences.*

1. State two ways through which the strength of an electromagnet can be increased.
2. State three factors on which, the magnitude of force on a current carrying conductor placed in a magnetic field, depends. Can this force be zero for some position of the conductor?
3. What do you mean by an electromagnet ? With the help of diagrams show the two types of electromagnets. Give two uses of electromagnets.
4. How will you experimentally show that a current-carrying conductor experiences a force when kept in a magnetic field?
5. Under what conditions permanent electromagnet is obtained

if a current carrying solenoid is used? Support your answer with the help of a labelled circuit diagram.

6. AB is a current carrying conductor in the plane of the paper as shown in Figure. What are the directions of magnetic fields produced by it at points P and Q? Given $r_1 > r_2$, where will the strength of the magnetic field be larger?

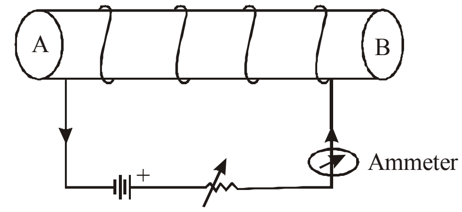


7. What does the divergence of magnetic field lines near the ends of a current carrying straight solenoid indicate?
8. List the properties of magnetic lines of force.
9. What is the magnetic field that exerts a force of 2.4×10^{-4} newtons on a current of 12 amperes in a wire 30 cm long set perpendicular to the field ?
10. A wire carrying 1.5 amp has a length of 20 cm in a magnetic field of 40 milliteslas. If the wire is perpendicular to the field, how much force does the field exert on the wire ?
11. What is the direction of the force that a vertical magnetic field, directed upward, will exert on an electron traveling eastward in it.
12. What is the shape of magnetic field lines around a circular current carrying conductor?
13. What is Solenoid?
14. Why is soft iron generally used as the core of the electromagnet?
15. State four factors on which the strength of electromagnet depends.
16. Explain different ways to induce current in a coil.
17. State the rule to determine the direction of a (i) magnetic field produced around a straight conductor-carrying current, (ii) force experienced by a current-carrying straight conductor placed in a magnetic field which is perpendicular to it, and (iii) current induced in a coil due to its rotation in a magnetic field.
18. Explain the underlying principle of an electric generator. What is the function of brushes?
19. What is electromagnetic induction ? Describe one experiment to demonstrate the phenomenon of electromagnetic induction.

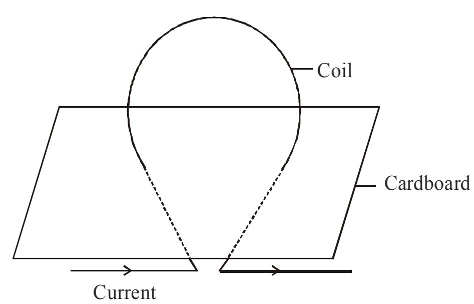
Long Answer Questions :

DIRECTIONS : *Give answer in 4 to 5 sentences.*

1. What is the nature of magnetic field produced by a straight current carrying conductor? Explain with the help of an experiment.
2. Diagram below shows a circuit containing a coil wound over a long and thin hollow carboard tube. Copy the diagram (i) Show the polarity acquired by each face of the solenoid. (ii) Draw the magnetic field lines of force inside the coil and also show their direction. (iii) Mention two methods to increase the strength of the magnetic field inside the coil.



3. A 0.4m wire, stretched horizontally, carries an electric current of 15A from east to west, in a magnetic field whose magnetic field intensity is 0.1 N/Am, directed vertically downwards. What is
   (a) the magnitude of the magnetic deflecting force on the wire, and
   (b) its direction?
4. A straight conductor passes vertically through a cardboard sprinkled with iron filings. Show the setting of the iron filings when a weak current is passed in the downward direction. What changes occur if,
   (i) the strength of the current is increased.
   (ii) the single conductor is replaced by several parallel conductors with current flowing in the same. direction.
5. The diagram shows a current carrying coil passing through a sheet of stiff cardboard. Draw three lines of magnetic field on the cardboard.



State two factors on which the magnitude of magnetic field at the centre of coil, depends.

6. Draw a labelled diagram to make an electromagnet from a soft iron bar. Mark the polarity at its ends. What precaution would you observe ?
7. What is an electric motor? With the help of diagram, explain its principle, construction and working.
8. What is D.C. generator? Explain its principle, construction and working with diagram.
9. What does the direction of thumb indicate in the right hand thumb rule. In what way this rule is different from Fleming's left-hand rule?
10. Explain with the help of a diagram, the principle and working of an a.c. generator.

2 EXERCISE

Text-Book Questions :

1. Why does a compass needle get deflected when brought near a bar magnet ?
2. Draw magnetic field lines around a bar magnet.
3. List the properties of magnetic lines of force.
4. Why don't two magnetic lines of force intersect each other ?
5. Consider a circular loop of wire lying in the plane of the table. Let the current pass through the loop clockwise. Apply the right-hand rule to find out the direction of the magnetic field inside and outside the loop.
6. The magnetic field in a given region is uniform. Draw a diagram to represent it.
7. Choose the correct option?
   The magnetic field inside a long straight solenoid-carrying current
   (a) is zero.
   (b) decrease as we move towards its end.
   (c) increases as we move towards its end.
   (d) is the same at all points.
8. Which of the following property of a proton can change while it moves freely in a magnetic field? (There may be more than one correct answer).
   (a) mass (b) speed
   (c) velocity (d) momentum
9. How the displacement of rod AB will be affected if (i) current in rod AB is increased, (ii) a stronger horse-shoe magnet is used, and (iii) length of the rod AB is increased?
10. A positively-charged particle (alpha-particle) projected towards west is deflected towards north by a magnetic field. The direction of magnetic field is
    (a) towards south (b) towards east
    (c) downward (d) upward
11. State Fleming's Left hand rule.
12. What is the principle of an electric motor?
13. What is the role of the split ring in an electric motor.
14. Explain the different ways to induce current in a coil.
15. State the principle of an electric generator.
16. Name some sources of direct current.
17. Which sources produce alternating current.
18. Choose the correct options?
    A rectangular coil of copper wires is rotated in a magnetic field. The direction of the induced current changes once in each
    (a) two revolutions (b) one revolution
    (c) half revolution (d) one-fourth revolution
19. Name two safety measures commonly used in electric circuits and appliances.
20. An electric oven of 2 kW power rating is operated in a domestic circuit (220 V) that has a current rating of 5 A. What result do you expect ? Explain.
21. What precaution should be taken to avoid the overloading of domestic electric circuits?

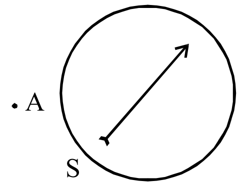
Text-Book Exercise :

1. Which of the following correctly describes the magnetic field near a long straight wire?
   (a) The field consists of straight lines perpendicular to the wire.
   (b) The field consists of straight lines parallel to the wire.
   (c) The field consists of radial lines originating from the wire.
   (d) The field consists of concentric circles centred on the wire.
2. The phenomenon of electromagnetic induction is
   (a) the process of charging a body.
   (b) the process of generating magnetic field due to a current passing through a coil.
   (c) producing induced current in a coil due to relative motion between a magnet and the coil.
   (d) the process of rotating a coil of an electric motor.
3. The device used for producing electric current is called a
   (a) generator (b) galvanometer
   (c) ammeter. (d) motor.
4. The essential difference between an AC generator and a DC generator is that
   (a) AC generator has an electromagnet while a DC generator has permanent magnet.
   (b) DC generator will generate a higher voltage.
   (c) AC generator will generate a higher voltage.
   (d) AC generator has slip rings while the DC generator has a commutator.
5. At the time of short circuit, the current in the circuit
   (a) reduces substantially.
   (b) does not change.
   (c) increases heavily.
   (d) very continuously.
6. State whether the following statements are true or false.
   (a) An electric motor converts mechanical energy into electrical energy.
   (b) An electric generator works on the principle of electromagnetic induction.
   (c) The field at the centre of a long circular coil carrying current will be parallel straight lines.
   (d) A wire with a green insulation is usually the live wire of an electric supply.

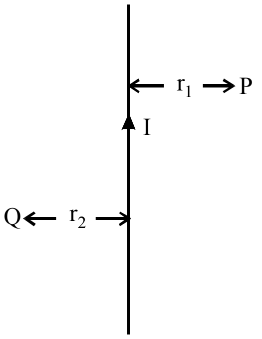
7. List three sources of magnetic fields.
8. How does a solenoid behave like a magnet? Can you determine the north and south poles of a current-carrying solenoid with the help of a bar magnet? Explain.
9. When is the force experienced by a current-carrying conductor placed in a magnetic field largest?
10. Imagine that you are sitting in a chamber with your back to one wall. An electron beam, moving horizontally from back wall towards the front wall, is deflected by a strong magnetic field to your right side. What is the direction of magnetic field?
11. Draw a labelled diagram of an electric motor. Explain its principle and working . What is the function of a split ring in an electric motor?
12. Name some devices in which electric motors are used.
13. A coil of insulated copper wire is connected to a galvanometer. What will happen if a bar magnet is (i) pushed into the coil (ii) withdrawn from inside the coil (iii) held stationary inside the coil?
14. Two circular coils A and B are placed close to each other. If the current in the coil A is changed, will some current be induced in the coil B? Give reason.
15. State the rule to determine the direction of a (i) magnetic field produced around a straight conductor carrying current, (ii) force experienced by a current carrying straight conductor placed in a magnetic field which is perpendicular to it, and (iii) current induced in a coil due to its rotation in a magnetic field.
16. Explain the underlying principle and working of an electric generator by drawing a labelled diagram. What is the function of brushes?
17. When does an electric short circuit occur?
18. What is the function of an earth wire? Why is it necessary to earth metallic appliances?

Exemplar Questions :

1. A magnetic compass needle is placed in the plane of paper near point A as shown in Figure. In which plane should a straight current carrying conductor be placed so that it passes through A and there is no change in the deflection of the compass? Under what condition is the deflection maximum and why?



2. Under what conditions permanent electromagnet is obtained if a current carrying solenoid is used? Support your answer with the help of a labelled circuit diagram.
3. AB is a current carrying conductor in the plane of the paper as shown in Figure. What are the directions of magnetic fields produced by it at point P and Q? Given $r_1 > r_2$, where will the strength of the magnetic field be larger?



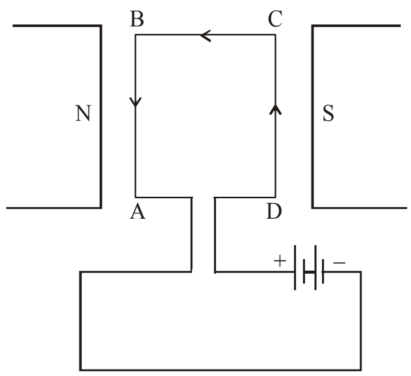
4. It is established that an electric current through a metallic conductor produces a magnetic field around it. Is there a similar magnetic field produced around a thin beam of moving (i) alpha particles, (ii) neutrons? Justify your answer.
5. What is the difference between a direct current and an alternating current? How many times does AC used in India change direction in one second?
6. Why does a magnetic compass needle pointing North and South in the absence of a nearby magnet get deflected when a bar magnet or a current carrying loop is brought near it. Describe some salient features of magnetic lines of field concept.

HOTS Questions :

1. Consider a circular loop of wire lying in the plane of the table. Let the current pass through the loop clockwise. Apply the right-hand rule to find out the direction of the magnetic field inside and outside the loop.
2. A current through a horizontal power line flows in east to west direction. What is the direction of magnetic field at a point directly below it and at a point directly above it ?
3. When is the force experienced by a current–carrying conductor placed in a magnetic field largest?
4. An electron in passing through a field but no forces acting on it. Under what condition it is possible, that the motion of the electron will be in the (i) electric field (ii) magnetic field?
5. A loop of irregular shape carrying current is located in an external magnetic field. If the wire is flexible, why does it change to a circular shape?
6. An electron does not suffer any deflection while passing through a region. Are you sure that there is no magnetic field? Is the reverse definite ?
7. Why is pure iron not used for making permanent magnets? Name one materials used for making permanent magnets. Describe how permanent magnets are made electrically. State two examples of electrical instruments made by using permanent magnets.
8. How does the strength of the magnetic field at the centre of a circular coil of wire depend on :
   (i) the radius of the coil
   (ii) the number of turns of wire in the coil
   (iii) the strength of current flowing in the coil ?

9. How will the magnetic field intensity at the centre of a circular coil carrying current change, if the current through the coil is doubled and the radius is halved?

10. A rectangular coil ABCD is placed between the pole pieces of a horse-shoe magnet as shown in figure.

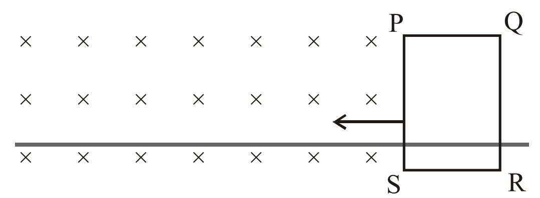


(i) What is the direction of force on each arm?
(ii) What is the effect of the forces on the coil?
(iii) How is the effect of force on the coil changed if the terminals of the battery are interchanged ?

11. If your metal car moves over a wide, closed loop of wire embedded in a road surface, will the magnetic field of the earth within the loop be altered? Will this produce a current pulse? Can you think of a practical application for this at a traffic intersection?

12. At the security area of an airport, you walk through a weak AC magnetic field inside a large coil of wire. What is the result of a small piece of metal on person that slightly alters the magnetic field in the coil?

13. The closed loop PQRS is moving into a uniform magnetic field acting at right angles to the plane of the paper as shown in the following figure. State the direction in which the induced current flows in the loop.



3 EXERCISE

Single Option Correct :

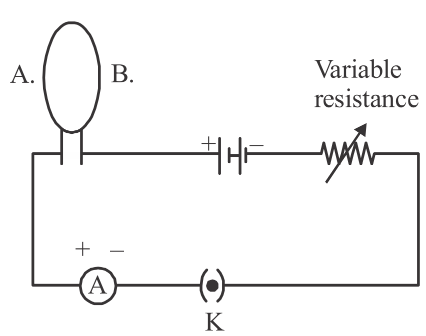
DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. Choose the correct option(s).
The magnetic field inside a long straight solenoid-carrying current
(a) is zero.
(b) decreases as we move towards its end.
(c) increases as we move towards its end.
(d) is the same at all points.

2. A positively-charged particle (alpha-particle) projected towards west is deflected towards north by a magnetic field. The direction of magnetic field is
(a) towards south (b) towards east
(c) downward (d) upward

3. Which of the following correctly describes the magnetic field near a long straight wire?
(a) The field consists of straight lines perpendicular to the wire.
(b) The field consists of straight lines parallel to the wire.
(c) The field consists of radial lines originating from the wire.
(d) The field consists of concentric circles centred on the wire.

4. A circular loop placed in a plane perpendicular to the plane of paper carries a current when the key is ON. The current as seen from points A and B (in the plane of paper and on the axis of the coil) is anti clockwise and clockwise respectively. The magnetic field lines point from B to A. The N-pole of the resultant magnet is on the face close to
(a) A
(b) B
(c) A if the current is small, and B if the current is large
(d) B if the current is small and A if the current is large



5. A small magnet is placed perpendicular to a uniform magnet field. The forces acting on the magnet will result in
(a) Rotational motion
(b) Translatory motion
(c) No motion at all
(d) Translational and rotational motion both

6. The magnetic field at a point due to a current carrying conductor is directly proportional to the
(a) current flowing through the conductor
(b) Distance from the conductor
(c) Voltage across the conductor
(d) Resistance of the conductor

7. Which one of the following substances is the magnetic substances?
(a) Mercury (b) Iron
(c) Gold (d) Silver

8. Magnetic lines do not intersect on one-another because
(a) they are at a distance
(b) they are in the same direction
(c) they are parallel to another
(d) at the point intersection there will be two direction of the magnetic force which is impossible

9. Instrument can be shielded from outside magnetic effects by surrounding them with
(a) Rubber shield (b) Glass shield
(c) Iron shield (d) Brass shield

10. By removing the inducing magnet, the induced magnetism is
(a) Finished after some time
(b) Finished just after
(c) Not finished for a long time
(d) Not changed

11. The effective length of the magnet is
(a) the complete length of the magnet
(b) the distance between the two poles of the magnet
(c) the half of the length of the magnet
(d) the square of the length of the magnet

12. When the bars of bismuth are placed between the magnetic poles they set their length
(a) perpendicular to the lines of force
(b) along the lines of force
(c) neither perpendicular nor along the lines of force
(d) In any direction

13. Which of the following processes will not produce new magnetic poles?
(a) cutting a bar magnet in half
(b) turning on a current in a solenoid
(c) running a current through a straight wire
(d) placing an iron rod in contact with a magnet

14. A tesla is equivalent to a
(a) newton per coulomb
(b) newton per ampere-meter
(c) ampere per newton
(d) newton per ampere-second

15. A vertical wire carries a current upward. The magnetic field north of the wire will be directed
(a) upward (b) eastward
(c) westward (d) northward

16. The magnetic flux is expressed in
(a) dynes (b) Oerested
(c) Gauss (d) Weber

17. The magnetic lines of force, inside a current carrying solenoid, are
(a) along the axis and are parallel to each other
(b) perpendicular to the axis and equidistance from each other
(c) circular and they do not intersect each other
(d) circular at the ends but they are parallel to the axis inside the solenoid.

18. Which of the following is not true
(a) Induction precedes attraction
(b) We cannot isolate a single pole
(c) We can magnetise an iron ring
(d) A permanent magnet retains its magnetism even when heated on a flame.

19. Which of the following statement is not correct about two parallel conductors carrying equal currents in the same direction?
(a) Each of the conductors will experience a force
(b) The two conductors will repel each other.
(c) There are concentric lines of force around each conductor
(d) Each of the conductors will move if not prevented from doing so

20. Which of the following determines the direction of magnetic field due to a current carrying conductor?
(a) Faraday's laws of electromagnetic induction
(b) Fleming's left-hand rule
(c) Lenz's rule
(d) Maxwell's cork screw rule

21. Along the direction of current carrying wire, the value of magnetic field is ?
(a) Zero
(b) Infinity
(c) Depends on the length of the wire
(d) Uncertain

22. To obtain maximum intensity of magnetic field at a point the angle between position vector of point and small elements of length of the conductor is
(a) 0 (b) $\pi/4$
(c) $\pi/2$ (d) π

23. The value of magnetic field due to a small element of current carrying conductor at a distance r and lying on the plane perpendicular to the element of conductor is
(a) zero
(b) maximum
(c) inversely proportional to the current
(d) none of the above

24. The value of intensity of magnetic field at a point due to a current carrying conductor depends
(a) Only on the value of current
(b) Only on a small part of length of conductor
(c) On angle between the line joining the given point to the mid point of small length and the distance between the small length of the point
(d) On all of the above

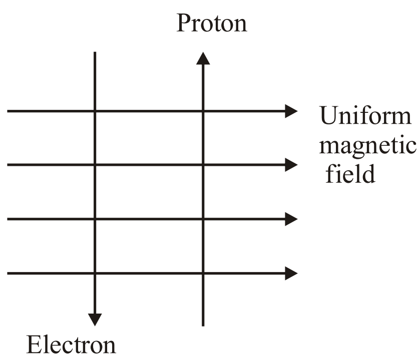
25. An electric current i is flowing in a circular coil of radius a. At what distance from the center of the axis of the coil will the magnetic field be $1/8^{th}$ of its value at the centre ?
(a) 3a (b) $\sqrt{3}$ a
(c) a/3 (d) $a/\sqrt{3}$

26. In a coaxial, straight cable, the central conductor and the outer conductor carry equal currents in opposite direction. The magnetic field is zero-
(a) outside the cable
(b) inside the inner conductor
(c) inside the outer conductor
(d) in between the two conductors

27. When the number of turns in a toroidal coil is doubled, the value of magnetic flux density will become
(a) four times (b) eight times
(c) half (d) double

28. By a current carrying toroid, whose area of cross-section is fixed, the magnetic induction produced will be -
(a) maximum at inner end
(b) maximum at outer end
(c) maximum at center of area of cross-section
(d) equal at whole area of cross-section

29. A uniform magnetic field exists in the plane of paper pointing from left to right as shown in Figure. In the field an electron and a proton move as shown. The electron and the proton experience
(a) forces both pointing into the plane of paper
(b) forces both pointing out of the plane of paper
(c) forces pointing into the plane of paper and out of the plane of paper, respectively
(d) force pointing opposite and along the direction of the uniform magnetic field respectively



30. When an electron beam is moving in a magnetic field, then the work done is equal to the
(a) charge of electron
(b) magnetic field
(c) product of electronic charge and the magnetic field
(d) zero

31. Which of the following rays are not deflected by a magnetic field -
(a) α-rays (b) β-rays
(c) γ-rays (d) positive rays

32. Two parallel beams of electron moving in the same direction will
(a) repel each other
(b) attract each other
(c) not interact with each other
(d) annihilate each other

33. An inverse square law of distance is obeyed by-
(a) the force per unit length between two long straight parallel current-carrying conductors in vacuum.
(b) the electric field intensity outside an isolated charged sphere
(c) the magnetic flux density outside a long straight current-carrying wire
(d) the electrostatic potential

34. A current carrying loop lying in a magnetic field behaves like a.
(a) A magnetic dipole (b) magnetic pole
(c) magnetic material (d) non-magnetic material

35. Two identical coaxial circular loops carry a current i each circulating in the same direction. If the loops approach each other, you will observe that
(a) the current in each increases,
(b) the current in each decreases,
(c) the current in each remains the same,
(d) the current in one increases whereas that in the other decreases

36. An induced e.m.f. is produced when a magnet is plunged into a coil. The strength of the induced e.m.f. is independent of
(a) the strength of the magnet
(b) number of turns of coil
(c) the resistivity of the wire of the coil
(d) speed with which the magnet is moved

37. The laws of electromagnetic induction have been used in the construction of a
(a) galvanometer (b) voltmeter
(c) electric motor (d) generator

38. The frequency of A.C. mains in India is
(a) 30 c/s (b) 50 c/s
(c) 60 c/s (d) 120 c/s

39. The phenomenon of electromagnetic induction is –
(a) the process of charging a body.
(b) the process of generating magnetic field due to a current passing through a coil.
(c) producing induced current in a coil due to relative motion between a magnet and the coil.
(d) the process of rotating a coil of an electric motor.

40. The device used for producing electric current is called a
(a) generator (b) galvanometer
(c) ammeter (d) motor

41. The direction of induced current is obtained by
(a) Fleming's left hand rule
(b) Right hand thumb rule
(c) Biot and Savart rule
(d) Fleming's right hand rule

42. In an electric motor, conversion takes place of
(a) Chemical energy into electrical energy
(b) Electrical energy into mechanical energy
(c) Electrical energy into light
(d) Electrical energy into chemical energy

43. The current in a generator armature is AC because
(a) the magnetic field reverses at intervals
(b) the current in the field coils is AC
(c) the rotation of the armature causes the field through it to reverse
(d) the commutator feeds current into it in opposite directions every half cycle

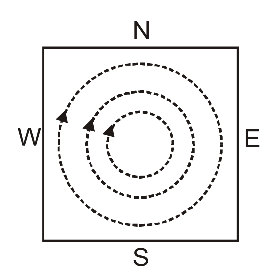
44. The current in the armature of a motor is reversed every half cycle due to the action of a(n)
(a) armature (b) field coil
(c) brush (d) commutator.

45. In an electric motor, the energy transformation is
(a) from electrical to chemical
(b) from chemical to light
(c) from mechanical to electrical
(d) from electrical to mechanical

46. The direction of induced current is obtained by
(a) Fleming's left hand rule
(b) Maxwell's cork-screw rule
(c) Ampere's rule
(d) Fleming's right hand rule

47. Direction of induced e.m.f. is determined by -
(a) Fleming's left hand rule
(b) Fleming's right hand rule
(c) Maxwell's rule
(d) Ampere's rule of swimming

48. A metal sheet is placed in a variable magnetic field which is increasing from zero to maximum. Induced current flows in the directions as shown in figure. The direction of magnetic field will be -



(a) normal to the paper, inwards
(b) normal to the paper, outwards
(c) from east to west
(d) from north to south

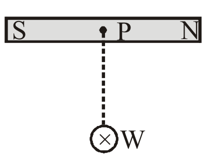
More than One Option Correct :

DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

1. Which of the following is/are valid for a current carrying circular coil?
(a) To induce magnetic induction of constant magnitude (at the centre of the coil), current required in it is directly proportional to its radius
(b) Induction of inducted magnetic field at the centre is inversely proportional to the radius of the coil
(c) Induction of the inducted magnetic field at the centre is directly proportional to the current flowing through the coil
(d) None of the above

2. A current flows along the length of a long thin cylindrical shell:
(a) magnetic field at all the points lying inside the shell is zero
(b) magnetic field at any point outside the shell varies inversely with distance from the surface of the shell
(c) magnetic field strength is maximum just outside the shell
(d) none of the above

3. Figure shows a bar magnet and a long straight wire W carrying current into the plane of the paper. Point P is the point of inersection of axis of the magnet and the line of the shortest distance between the magnet and the wire.



Which of the following statements is/are correct?
(a) If P is the midpoint of the magnet, the magnet experiences no torque
(b) If P is on the left of the midpoint of the magnet, the magnet experiences a leftward force as well as a torque
(c) If P is the midpoint of the magnet, the magnet experience a force along the line of the shortest distance
(d) None of the above

4. A straight conductor carries a current. Assume that all free electrons in the conductor move with the same drift velocity v. A and B are two observers on a straight line XY parallel to the conductor. A is stationary. B moves along XY with a velocity v in the direction of the free electrons.
(a) A and B observe the same magnetic field
(b) A observes a magnetic field, B does not
(c) A and B observe magnetic fields of the same magnitude but opposite directions
(d) A and B do not observe any electric field

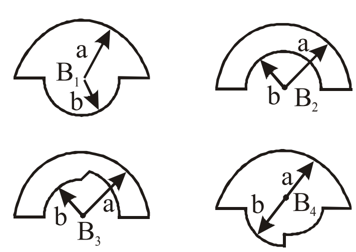
5. A charged particle enters into a space and continues to move undeflected. Then in that space:
(a) a uniform horizontal electric field and a vertical magnetic field may be present
(b) a vertical electric field alone may be present
(c) uniform electric and magnetic fields, both directed vertically downwards, may be present
(d) a uniform horizontal magnetic field alone may be present

6. A flat circular coil carrying a current has a magnetic moment μ:
(a) μ has only magnitude; it does not have direction
(b) the direction of μ is along the normal to the plane of the coil
(c) the direction of μ depends on the direction of current flow
(d) the direction of μ does not change if the current in the coil is reversed

7. A current carrying ring is placed in a magnetic field. The direction of the field is perpendicular to the plane of the ring:
(a) there is no net force on the ring
(b) the ring will tend to expand
(c) the ring will tend to contract
(d) either (b) or (c) depending on the directions of the current in the ring and the magnetic field

8. A solenoid is connected to a source of constant e.m.f. for a long time. A soft iron piece is inserted into it. Then:
(a) self-inductance of the solenoid gets increased
(b) flux linked with the solenoid increases; hence, steady state current gets decreased
(c) energy stored in the solenoid gets increased
(d) magnetic moment of the solenoid gets increased

9. In the loops shown in figure all curved sections are either semicircles or quarter circles. All the loops carry the same current. The magnetic fields at the centres have magnitudes B_1, B_2, B_3 and B_4:



(a) B_4 is maximum (b) B_3 is minimum
(c) $B_4 > B_1 > B_2 > B_3$ (d) $B_1 > B_4 > B_3 > B_2$

10. In which of the following cases does the electromagnetic induction occur –
(a) a current is started in a wire held near a loop of wire
(b) the current is stopped in a wire held near a loop of wire
(c) a magnet is moved through a loop of wire
(d) a loop of wire is held near a magnet

Passage Based Questions :

DIRECTIONS : *Study the given paragraph(s) and answer the following questions.*

Passage - I

Take a tightly-wound solenoid of radius a and length ℓ. the number of turns per unit length in it is n. It carries current i. Consider a small element of length dx of the solenoid at a distance x from one end. This contains ndx turns and can be assumed as a current carrying loop. The magnetic field due to whole solenoid will be the sum of magnetic field due to such elements.

1. The magnetic field due to this solenoid at the centre of its axis is :

(a) $\frac{\mu_0 i}{2a}$ (b) $\frac{\mu_0 n i}{2a}$

(c) $\frac{\mu_0 ni}{\sqrt{1+\frac{a^2}{\ell^2}}}$ (d) $\frac{\mu_0 n i}{\sqrt{1+\frac{4a^2}{\ell^2}}}$

2. The magnetic field due to the solenoid at the centre of its axis in the situation $a >> \ell$ is :

(a) $\frac{\mu_0 n i}{2}$ (b) $\mu_0 ni$

(c) $\frac{\mu_0 ni\ell}{2a}$ (d) $\frac{\mu_0 ni\ell}{a}$

3. The magnetic field due to the solenoid at the centre of its axis in the situation a << ℓ is :

(a) zero (b) $\frac{\mu_0 n i}{2}$

(c) $\mu_0 ni$ (d) infinite

Assertion & Reason :

DIRECTIONS : *Each of these questions contains an Assertion followed by reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.
(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.
(c) If **Assertion** is **correct** but **Reason** is **incorrect**.
(d) If **Assertion** is **incorrect** but **Reason** is **correct**.

1. **Assertion :** A direction current flows through a metallic rod, produced magnetic field only outside the rod.
Reason : There is no flow of charge carriers inside the rod.

2. **Assertion :** Force experienced by moving charge will be maximum if direction of velocity of charge is perpendicular to applied magnetic field.
Reason : Force on moving charge is independent of direction of applied magnetic field.

3. **Assertion :** A neutral body may experience a net nonzero magnetic force.
Reason : The net charge on a current carrying wire is zero, but it can experience a force in a magnetic field.

4. **Assertion :** There is no change in the energy of a charged particle moving in a magnetic field although a magnetic force is acting on it.
Reason : Work done by centripetal force is always zero.

5. **Assertion:** When two long parallel wires, hanging freely are connected in series to a battery, they come closer to each other.
Reason : Wires carrying current in opposite direction repel each other.

6. **Assertion :** A solenoid tends to expand, when a current passes through it.
Reason : Two straight parallel metallic wires carrying current in same direction attract each other.

7. **Assertion :** In a conductor, free electrons keep on moving but no magnetic force acts on a conductor in a magnetic field.
Reason: Force on free electrons due to magnetic field always acts perpendicular to its direction of motion.

8. **Assertion :** A small coil carrying current, in equilibrium, is perpendicular to the direction of the uniform magnetic field.
Reason : Torque is maximum when plane of coil and direction of the magnetic field are parallel to each other.

9. **Assertion :** Basic difference between an electric line and magnetic line of force is that former is discontinuous and the later is continuous or endless.
Reason : No electric lines of force exist inside a charged body but magnetic lines do exist inside a magnet.

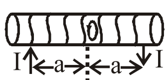
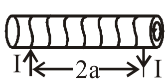
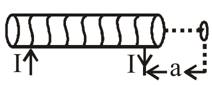
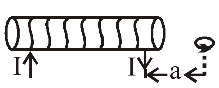
10. **Assertion :** No net force acts on a rectangular coil carrying a steady current when suspended freely in a uniform magnetic field.
Reason : Force on coil in magnetic field is always non-zero.

11. **Assertion :** An induced current has a direction such that the magnetic field due to the current opposes the change in the magnetic flux that induces the current.
Reason : Above statement is in accordance with conservation of energy.

Multiple Matching Questions :

DIRECTIONS : *Following question has four statements (A, B, C and D) given in Column I and four statements (p, q, r and s) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

1. In column I, the positions of small current carrying loops have been shown and in column II information related to force experienced by coil is given. Match the entries of column I with the entries of column II. (Assume solenoid radius to be small as compared to its length)

Column-I	Column-II
A. 	(p) Attractive
B. 	(q) Repulsive
C. 	(r) Zero
D. 	(s) Initially zero, then starts increasing

	A	B	C	D
(a)	p	q	r	s
(b)	p, q	t	s	r
(c)	r	p	p	s
(d)	t	q, r	p, s	q

Integer/ Numeric Questions :

DIRECTIONS : *Following are integer based/Numeric based questions. Each question, when worked out will result in one integer or numeric value.*

1. The energy of a charged particle moving in a uniform magnetic field does not change. Explain

2. The flow of a current in a circular loop of wire creates a magnetic field at its centre. How may existence of this field be detected? State the rule which helps to predict the direction of this magnetic field.

3. A force of 1N is exerted on a conductor of length 3 m carrying a current of 2A when placed in a magnetic field. Find the strength of field?

4. A coil of radius 22 cm has 14 turns. Find strength of field if 5A current is flowing through the coil?

5. A circular coil of wire of radius 0.05 m having 500 turns carries a current of 1A. Calculate the magnetic field at the centre of the coil?

6. Find magnetic field in air 0.01 m away from an infinitely long wire that carries a current of 2A?

7. The radius of a circular coil having 20 turns is 15 cm. If a current of 60A is flowing through this circular coil, calculate the magnetic field produced at its centre?

8. A wire of length 0.04 m is placed perpendicular to a uniform magnetic field of magnitude 0.30 T? Calculate the force on the wire when the current flowing through it is 5A.

9. A particle having a charge of 1.6×10^{-19} coulomb is moving with a speed of 3.5×10^{7} m/s in a magnetic field of 4T. Calculate the force experienced by this moving charged particle?

4 ADVANCED EXERCISE
BASED ON CONNECTING TOPICS

DIRECTIONS (Qs. 1-23) : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. A magnet is placed vertically on a paper. Then the number of neutral points obtained on the paper is
(a) zero (b) one
(c) two (d) three

2. A charge of 1.6×10^{-19} coulomb enters in the magnetic field of 2 weber/m² normally with a velocity of 10^5 m/sec. The force on the charge will be
(a) 3.2×10^{-14} N (b) 3.2×10^{-19} N
(c) 1.6×10^{-14} N (d) zero

3. The vertical plane which passes through the magnetic axis of a freely suspended magnet at rest is called
(a) Magnetic meridian (b) Geographical meridian
(c) North meridian (d) South meridian

4. The similar magnets of steel are .... than the magnets of soft iron
(a) stronger (b) of equal strength
(c) weaker (d) none of the above

5. A bar of soft iron is placed flat on the table. A bar magnet is taken and its south pole is placed on one end of the bar of soft iron. The magnet is held almost vertically. The bar is stroked from one end to the other with magnet. On the other end of the bar, magnet is lifted and again placed on the first end and the bar is again stroked. The end of the bar where the magnet is lifted will be
(a) south pole
(b) no pole
(c) south and north both type
(d) north pole

6. The angle of decilination at a place is the angle
(a) between the vertical plane and the geographical meridian
(b) between the vertical plane and the magnetic meridian
(c) between the geographical meridian and the magnetic meridian
(d) between the geographical meridian and horizontal plane

7. The magnetism in a magnet is mainly due to
(a) The orbital motion of the electrons
(b) The spin motion of the electrons
(c) The nuclear charge
(d) None of the above

8. When the north pole of a strong magnet is brought near to the north pole of a weak magnet then they will
(a) Attract each other
(b) repel each other
(c) first attract and then repel
(d) first repel and then attract

9. The angle of inclination of the axis of the magnetic needle to the horizontal plane when suspended freely and is at rest is known as
(a) angle of inclination (b) angle of variation
(c) angle of declination (d) none of the above

10. Which of the following statement is not correct?
(a) The dip angle is the angle between the horizontal and earth's total magnetic field.
(b) Neutral points are obtained where the earth's magnetic field is perpendicular to that due to a magnet
(c) A magnetic field is a region in which a magnetic force can be detected.
(d) Magnetic fields are vector quantities

11. When a bar magnet is broken into two pieces?
(a) we will have a single pole on each piece
(b) each piece will have two like poles
(c) each piece will have two unlike poles
(d) each piece will be lose magnetism

12. The permanent magnets are kept with soft iron pieces at ends as keepers
(a) to magnetise the soft iron pieces
(b) to increase the strength of the magnets
(c) to avoid self demagnetisation
(d) for physical safety of the magnets

13. The vertical component of the earth's magnetic field is
(a) zero at the magnetic pole
(b) zero at the geographic pole
(c) same everywhere
(d) zero at the magnetic equator

14. A small piece of a substance gas repelled when it is brought near a powerful magnet. The substance can be
(a) dimagnetic (b) paramagnetic
(c) ferromagnetic (d) non-magnetic

15. Whenever the magnetic flux linked with a coil changes, an induced e.m.f. is produced in the circuit. The e.m.f. lasts
(a) for a short time
(b) for a long time
(c) for ever
(d) so long as the change in flux takes place

16. A magnet is moved towards a coil (i) quickly (ii) slowly, then the induced e.m.f. is
(a) larger in case (i)
(b) smaller in case (i)
(c) equal in both the cases
(d) larger or smaller depending upon the radius of the coil

17. Lenz's law is a consequence of the law of conservation of
(a) charge (b) mass
(c) energy (d) momentum

18. The laws of electromagnetic induction have been used in the construction of a
(a) galvanometer (b) voltmeter
(c) electric motor (d) generator

19. Whenever, current is changed in a coil, an induced e.m.f. is produced in the same coil. This property of the coil is due to
(a) mutual induction (b) self induction
(c) eddy currents (d) hysteresis

20. If N is the number of turns in a coil, the value of self inductance varies as
(a) N^0 (b) N
(c) N^2 (d) N^{-2}

21. The SI unit of inductance, henry, can be written as
(a) weber/ampere (b) volt second/ampere
(c) joule/ampere^2 (d) all of these

22. Two coils are placed close to each other. The mutual inductance of the pair of coils depends upon
(a) relative position and orientation of the two coils.
(b) the materials of the wires of the coils.
(c) the currents in the two coils
(d) the rates at which currents are changing in the two coils

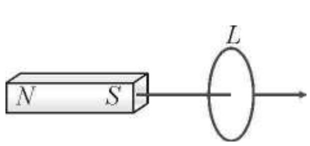
23. The current in a generator armature is AC because
(a) the magnetic field reverses at intervals
(b) the current in the field coils is AC
(c) the rotation of the armature causes the field through it to reverse
(d) the commutator feeds current into it in opposite directions every half cycle

DIRECTIONS (Qs. 24-27): *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

24. A proton moving with a constant velocity passes through a region of space without any change in its velocity. If E and B represent the electric and magnetic fields repectivelmy, this region of space may have:
(a) $E=0, B=0$ (b) $E=0, B\neq 0$
(c) $E\neq 0, B=0$ (d) $E\neq 0, B\neq 0$

25. In which of the following cases does the electromagnetic induction occur –
(a) a current is started in a wire held near a loop of wire
(b) the current is stopped in a wire held near a loop of wire
(c) a magnet is moved through a loop of wire
(d) a loop of wire is held near a magnet

26. Figure shows a loop model (loop L) for a diamagnetic material.



(a) The net dipole moment of the loop directed towards the magnet
(b) The net dipole moment of the loop directed away from the loop
(c) The loop gets attracted towards the magnet
(d) The loop gets repelled by the magnet.

27. Which of the following statements are true about the magnetic susceptibility χ_m of paramagnetic substance
(a) value of χ_m is inversely proportional to the absolute temperature of the sample
(b) χ_m is positive at all temperature
(c) χ_m is negative at all temperature
(d) χ_m does not depend on the temperature of the sample

DIRECTIONS (Qs. 28-33) : *Study the given paragraph(s) and answer the following questions.*

Passage - I

In a television tube, each of the electrons in the beam has a kinetic energy of 12.0 keV. The tube is oriented so that the electrons move horizontally from geomagnetic south to geomagnetic north. The vertical component of earth's magnetic field points down and has a magnitude of 55.0 μT.

28. The direction in which beam deflects :
(a) east (b) west
(c) north-east (d) south-west

29. The acceleration of any electron due to the magnetic field is :
(a) $3.14\times 10^{14}\,m/s^2$ (b) $4.28\times 10^{14}\,m/s^2$
(c) $5.56\times 10^{12}\,m/s^2$ (d) $6.28\times 10^{14}\,m/s^2$

30. The transverse deflection of the beam after travelling 20.0 cm through the television tube :
(a) 1.96 mm (b) 2.98 mm
(c) 4.24 mm (d) none of these

Passage II

Modern Trains are based on Maglev technology in which trains are magnetically leviated, which runs its EDS Maglev System. These are coils on both sides of wheels. Due to motion of train current induces in the coil of track which levitate it. This is in accordance with Lenz's law. If trains lower down, then due to Lenz's law a repulsive force increases due to which train gets uplifted and if it goes much high then there is a net downward force due to gravity. The advance of Maglev train is that there is no friction ebtween the trains and the track, thereby reducing power consumption and enabling the train to attain very high speeds. Disadvantage of Maglev train is that as it slows down the electromagnetic force decreases and it become difficult to keep it leviated and as it moves forwards, according to Lenz's law there is an electromagnetic drop force.

31. What is the advantage of this system?
(a) No friction, hence no power consumption
(b) No electric power is used
(c) Gravitation force is zero
(d) Electrostatic force draws the train

32. What is the disadvantage of this system?

(a) Train experiences an upward force according to Lenz's law
(b) Friction force creates a drag on the train
(c) Retardation
(d) By Lenz's law, train experiences a drag

33. Which force causes the train to elevate up?

(a) Electrostatic force
(b) Time varying electric field
(c) Magnetic force
(d) Induced electric field

DIRECTIONS (Qs. 34-37): *Each of these questions contains an Assertion followed by reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.
(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.
(c) If **Assertion** is **correct** but **Reason** is **incorrect**.
(d) If **Assertion** is **incorrect** but **Reason** is **correct**.

34. **Assertion :** A proton moves horizontally towards a vertical long conductor having an upward electric current. It will deflect vertically downward.
Reason : Seeing the proton and the conductor from the side of the proton, the magnetic field at the site of the proton will be towards right. Hence the force $\vec{F} = q\vec{v} \times \vec{B}$ will deflect the proton vertically downward.

35. **Assertion :** An induced e.m.f. appears in any coil in which the current is changing.
Reason : Self induction phenomenon obeys Faraday's law of induction.

36. **Assertion :** Lenz's law violates the principle of conservation of energy.
Reason : Induced e.m.f. always opposes the change in magnetic flux responsible for its production.

37. **Assertion :** When number of turns in a coil is doubled, coefficient of self-inductance of the coil becomes 4 times.
Reason : This is because $L \propto N^2$.

DIRECTIONS (Qs. 38-39) : *Following question has four statements (A, B, C and D) given in Column I and four statements (p, q, r and s) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

38. In magnetic field, for a charged particle, match the entries of column I with the entries of column II.

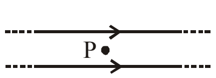
Column I	**Column II**
(A) Acceleration	(p) may be zero
(B) Velocity	(q) is zero
(C) Speed	(r) may be constant
(D) Kinetic energy	(s) is constant

	A	B	C	D
(a)	p	r	s	s
(b)	s	p	q	r
(c)	p, q	s	r, s	q
(d)	q, s	q, r	s	s

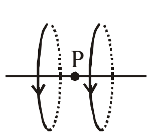
39. Two wires each carrying a steady current I are shown in four configurations in Column I. Some of the resulting effects are described in Column II. Match the statements in Column I with the statements in column II

Column I

(A) Point P is situated midway between the wires.



(B) Point P is situated at the mid-point of the line joining the centers of the circular wires, which have same radii.

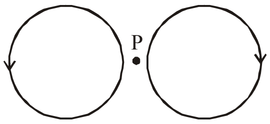


Column II

(p) The magnetic fields (B) at P due to the currents in the wires are in the same direction.

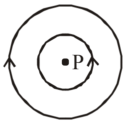
(q) The magnetic fields (B) at P due to the currents in the wires are in opposite directions.

(C) Point P is situated at the mid-point of the line joining the centers of the circular wires, which have same radii.



(r) There is no magnetic field at P.

(D) Point P is situated at the common center of the wires.



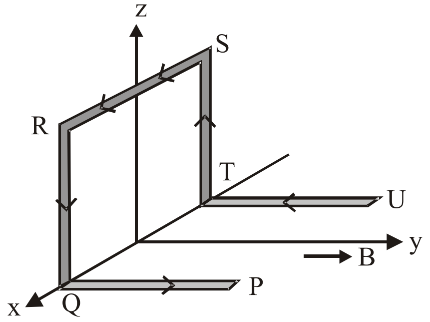
(s) The wires repel each other.

	A	B	C	D
(a)	p, r	r, s	q, s	s
(b)	s	p	q	r
(c)	q, r	p	q, r	q, s
(d)	q, s	q, r	s	s

DIRECTIONS (Qs. 40-45): *Following are integer based/Numeric based questions. Each question, when worked out will result in one integer or numeric value.*

40. At a certain position, earth's magnetic field of 39 μT is horizontal and directed due north. Suppose the net field is zero exactly 8.0 cm above a long, straight, horizontal wire that carries a constant current. What are (a) the magnitude and (b) the direction of the current ?

41. A wire PQRSTU (with each side of length L) bent as shown in figure and carrying a current I is placed in a uniform magnetic field B parallel to positive y direction. What is the force experienced by the wire?



42. An electron is projected with a velocity of 10^5 m/s at right angles to a magnetic field of 0.019G . Calculate the radius of the circular path described by the electron, if charge of electron $e = 1.6\times10^{-19}$ C, and mass of electron $m = 9.1 \times 10^{-31}$ kg.

43. Find the self inductance of a coil in which an e.m.f. of 10 V is induced when the current in the circuit changes uniformly from 1 A to 0.5 A in 0.2 sec.

44. The mutual inductance of a pair of coils is 0.75 H. If current in the primary coil changes from 0.5 A to zero in 0.01 s find average induced e.m.f. in secondary coil.

45. An AC generator of 220 V having internal resistance $r = 10\Omega$ and external resistance $R = 100\Omega$. What is the power developed in the external circuit?

SOLUTIONS

Brief Explanations of Selected Questions

1 EXERCISE

Fill in the Blanks :

1. small **2.** magnetic field
3. greater. **4.** magnetic
5. right-hand **6.** north magnetic
7. electromagnets **8.** tesla
9. Weber **10.** magnetic
11. S **12.** field, current
13. downward **14.** currents
15. clockwise **16.** increase
17. circles **18.** None
19. south
20. electrical, electromagnetic induction.
21. 220 V, 50 Hz. **22.** 60 Hz
23. magnetic **24.** commutator
25. A.C **26.** self-induction
27. henry **28.** the magnetic flux
29. 90

True / False :

1.	True	**2.**	True	**3.**	False	**4.**	True
5.	False	**6.**	True	**7.**	True	**8.**	True
9.	True	**10.**	False	**11.**	True	**12.**	False
13.	True	**14.**	True	**15.**	True	**16.**	True
17.	False	**18.**	False	**19.**	False		

Match the Following :

1. (A) $\rightarrow$ q, (B) $\rightarrow$ s, (C) $\rightarrow$ r, (D) $\rightarrow$ p
2. (A) $\rightarrow$ r, (B) $\rightarrow$ q, (C) $\rightarrow$ s, (D) $\rightarrow$ p
3. (A) $\rightarrow$ r, (B) $\rightarrow$ q, (C) $\rightarrow$ r, (D) $\rightarrow$ p

Very Short Answer Questions :

1. A compass needle gets deflected when brought near a bar magnet because magnetic force is exerted by the bar magnet on the compass needle, which is itself a tiny pivoted magnet.

2. The current is in the east-west direction. Applying the right-hand thumb rule, we get that the direction of magnetic field at a point below the wire is from north to south. The direction of magnetic field at a point directly above the wire is from south to north.

3. Two magnetic lines of force never intersect each other. If the lines intersect, then at the point of intersection there would be two directions (the needle would point towards two directions) for the same magnetic field, which is not possible.

4. Direction of magnetic field inside the loop – Perpendicular to the plane of paper inward and
Direction of magnetic field outside the loop – Perpendicular to the plane of paper outward.

5. (a) Natural and artificial magnets. (b) Electromagnets (c) A current carrying conductor produces magnetic field.

6. The force experienced by a current-carrying conductor placed in a magnetic field is largest when the direction of current is at right-angles to the direction of the magnetic field.

7. Oersted's experiment demonstrates the magnetic effect of current. It showed experimentally that the current flowing through a conductor produces a magnetic field.

8. (i) Bar type (ii) Horse shoe type

13. (i) Along the axis of the coil inwards
(ii) Along the axis of the coil outwards.

15. Magnetic field lines at any point constitute the field of a magnet indicating that a north pole experiences a force at that point.

16. Magnetic field. It is a vector quantity.

17. Fleming's left hand rule.

18. M, B, I are represented by thumb, forefinger and middle finger of the right hand.

19. The A.C. generator has two slip rings.

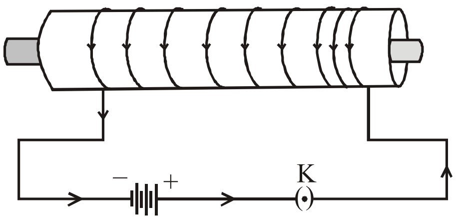
20. Frequency of an alternating current is 50 Hz. It changes the direction after every sec. i.e. the direction of current change 100 times per second.

21. 50 Hz.

22. Anticlockwise from the side of the magnet.

Short Answer Questions :

5. (i) The current through the solenoid should be direct current.
(ii) The rod inside is made of a magnetic material such as steel.



6. Into the plane of paper at P and out of it at Q. The strength of the magnetic field is larger at the point located closer i.e. at Q.

7. The divergence, that is, the falling degree of closeness of magnetic field lines indicates the fall in strength of magnetic field near and beyond the ends of the solenoid.

8. (i) The direction of the magnetic field is indicated by the arrow in the line at any point (Tangent).

(ii) The field lines come out of the north pole and get into the south pole (closed loops are formed).

(iii) The strength of magnetic field is indicated by the closeness of the field lines. Closer the lines, more will be the strength and farther the lines, lesser will be the field strength.

(iv) No two field lines will intersect each other if they intersect there will be two different directions for field at the same point which is not impossible.

9. The current is perpendicular to the field, $B = \dfrac{F}{I\ell}$

Therefore, $B = \dfrac{2.4 \times 10^{-4}\,N}{(12A)\,(0.30m)} = 6.7 \times 10^{-5}\,N/A.m$

Since 1mT is 10^{-3} N/A.m, the answer can be written as 0.067 mT

10. With the wire perpendicular to the field,

$$F = I\ell B = (1.5A)\,(0.20m)\,(0.040T) = 0.012\ N$$

11. Point you left fingers upward, since your are dealing with a negative charge. Rotate your hand until the thumb points east. Your palm will point northward, and that is the direction of the force.

12. Concentric lines around the two ends of the conductor and straight lines at the centre of the conductor.

13. A cylindrical coil of many tightly wound turns of insulated wires with generally diameter of the coil smaller than its length is called a solenoid.

14. (i) Soft iron has less retentivity so it acquires the magnetic properties only when the current flows through the coil wound on it and loses the magnetic properties as the current is switched off.

(ii) The soft iron intensifies the magnetic field of the electromagnet because of its high permeability.

15. Factors on which the strength of an electromagnet depends are:

(1) Strength of electromagnet is directly proportional to the diameter of coil (Area of cross-section).

(2) Strength of an electromagnet depends upon the nature of the core.

(3) Strength of an electromagnet is directly proportional to the number of turns in coil.

(4) Strength of electromagnet is directly proportional to current.

16. (i) A current is induced in a coil when a magnet is moved relative to the fixed coil.

(ii) A current is also induced in a coil when it is moved relative to a fixed magnet.

(iii) Not any current is induced in a coil when the coil and magnet both are stationary relative to one another.

(iv) When the direction of motion of magnet or coil is reversed, the direction of current induced in the coil also gets reversed.

17. (i) The direction of magnetic field produced around a current-carrying conductor is given by right hand thumb rule. If the conductor carrying current is held in the right hand in such a way that the thumb points in the direction of current, then direction of curl of fingers gives the direction of the magnetic field.

(ii) The direction of force experienced by a straight conductor carrying-current placed in a magnetic field, which is perpendicular to it determined by Fleming's left hand rule. Hold the thumb and first two fingers of the left hand at right angles to each other with the first finger pointing the direction of the field and the second finger in the direction of the current, then the thumb points in the direction of the motion.

(iii) The direction of current induced in a circuit by changing magnetic flux due to motion of a magnet is determined by Fleming's right-hand rule. If we stretch our right hand in such a way that the thumb, forefinger and central finger remain perpendicular to echo other, so that the forefinger indicates the direction of the magnetic field and the thumb in the direction of motion of conductor. Then the central finger indicates the direction of induced current.

18. Principle : It is based on the principle of electromagnetic induction, which is the process of producing induced current in a coil by relative motion between a magnet and the coil. Function of brushes : The brushes carry the contact from rings to external load resistance.

Long Answer Questions :

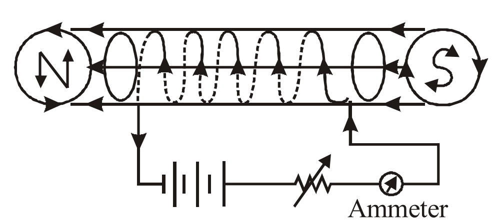
1. The magnetic field produced around a straight current carrying conductor is in the form of concentric circles with the centre lying on the straight conductor.

Take a copper wire AB. Pass it through a cardboard. Connect the wire to a battery through a key. Sprinkle some iron filings on the cardboard. Switch on the key and tap the cardboard gently. You will find that the iron filings arrange themselves in the form of concentric circles. Reverse the direction of current by changing the polarity of the battery. You will find that this time too, the iron filings arrange themselves in concentric circle but in opposite direction.

Hence, the magnetic field lines of force around a straight conductor carrying electric current are concentric circles with the conductor at the centre. The direction of magnetic field changes if the direction of current is reversed.

2. (i) The polarity acquired by the two ends is as shown below. (A shows North and B shows South polarity

(ii)

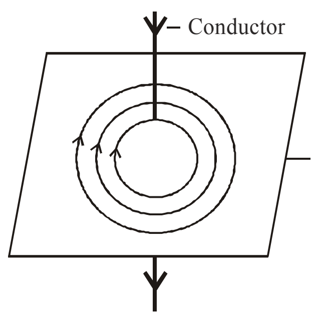


(iii) Increase the strength of current, increase the number of turns in the coil, insert soft iron rod in the coil.

3. (a) Given : Length of the wire $(\ell) = 0.4$ m
Current (I) = 15A
Magnetic induction (B) = 0.1 N/Am
To calculate : (i) Force (F) = ? (ii) Direction = ?
Formula to be used : $F = BI\ell$
Substituting the given values,
$F = 0.1 \times 15 \times 0.4 = 0.6$ N

(b) By Fleming's left hand rule, forefinger (magnetic field) points vertically downwards, the middle finger (current) points west and the thumb (force) points towards the south.

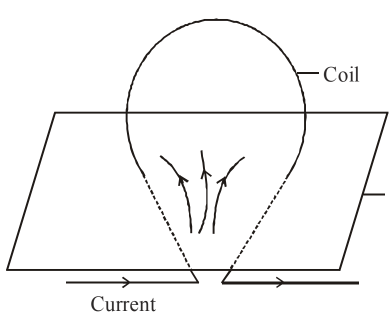
4. Figure shows the setting of the iron filings.



(i) The shape of distribution of iron filings remains unchanged but they get arranged upto a larger distance from the conductor when the strength of current is increased. This is because on increasing the strength of current, the strength of the magnetic field is increased and it is effective upto a larger distance from the conductor.

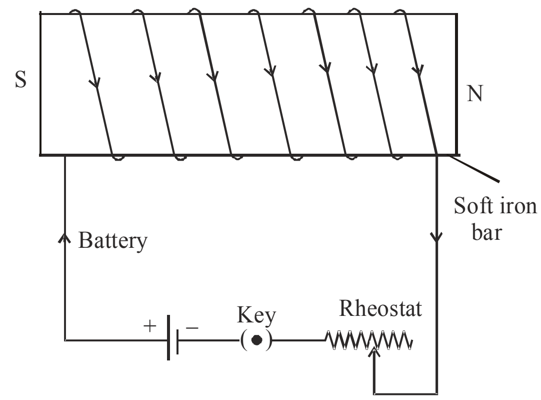
(ii) Magnetic field strength is increased so the iron filings get arranged upto a larger distance.

5. Figure represents the magnetic lines of force due to current carrying coil.



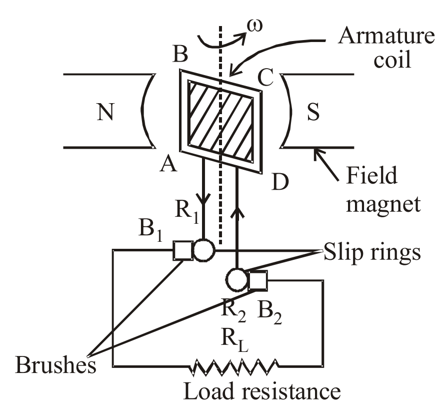
The magnitude of magnetic field at the centre depends on (i) the strength of current in the coil and (ii) the radius of coil.

6. The labelled diagram is shown in figure.



Precaution : The source of current must be the d.c. source.

10.



Principle: A dynamo or generator is a device which converts mechanical energy into electrical energy. It is based on the principle of electromagnetic induction.

Construction: It consists of four main parts-

(i) Field magnet: It produces the magnetic field. For a low power dynamo, the magnetic field in generated by a permanent magnet but for a large power dynamo, the magnetic field is produced by an electromagnet.

(ii) Armature: It consists of a large number of turns of insulated copper wire on a soft iron core. It can revolve round the axis between the two poles of the field magnet. The soft iron core provides support to the coils and increases the magnetic field through the coil.

(iii) Slip rings: The slip rings R_1 and R_2 are two metal rings to which the ends of the 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 (B_1 and B_2): These are flexible metal plates or carbon rods which are fixed and constantly touch the revolving rings. The output current in external load resistance R_1 is taken through these brushes.

Working: When the armature coil is rotated in the strong magnetic field, the magnetic flux linked the coil changes and the current is induced in the coil. The direction of current is given by Flemming's left hand rule. It remains same during the first half turn of the armature. During the second half revolution, the direction of current is reversed.

If N is the number in the coil, f is the frequency of rotation, A is the area of the coil and B is the magnetic field intensity then induced e.m.f..

$$e = -\frac{d\phi}{dt} = \frac{d}{dt}(\text{NBA} \cos 2pft) = 2p\text{NBA}f \sin 2pft$$

Therefore, the e.m.f. produced is alternating in nature and the current is also alternating.

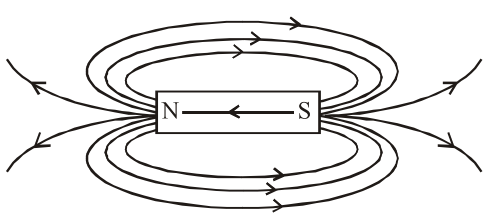
Current produced in a.c. generator can not be measured by moving coil galvanometer, because average value of a.c. over full cycle is zero.

2 EXERCISE

Text-Book Questions :

1. Compass needle is a tiny magnet, so due to force of repulsion or attraction between the poles of a magnet, there is a deflection in the compass needle.

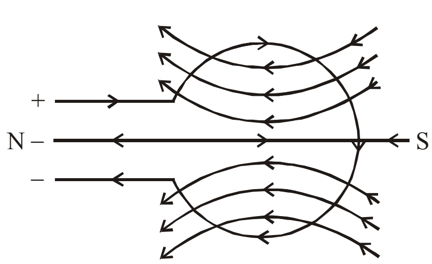
2.



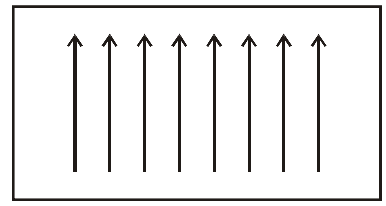
3. Magnetic field lines emerge from N-pole and enter S-pole. The magnetic field strength is represented diagrammatically by the degree of closeness of the field lines. Field lines cannot cross each other as two values of net field at a single point cannot exist. Only one value, a unique net value, can exist. If in a given region, lines of field are shown to be parallel and equispaced, the field is understood to be uniform.

4. Because we cannot have two directions of the magnetic field at the same point.

5.



6.



Magnetic field lines are parallel straight lines for a uniform field. The lines are closer for a strong field and for away for a weak one.

7. (d)

8. (b, c, d)

9. We know that when a current carrying conductor is kept in a magnetic field, the force acting on it is given by

$F = BIL$

(i) $F \propto I$ I increases then force increases, hence, displacement is more

(ii) $F \propto B$ B increases then force increases, hence, displacement is more

(iii) $F \propto L$ L increases then force increases, hence, displacement is more

10. (d) upward, according to the Fleming's Right Hand Thumb Rule.

11. Refer to theory.

12. Refer to theory.

13. The split ring acts as a commutator. The reversal of current also reverses the direction of force acting on the arms of the coil. At this stage, the commutator reverses the direction of currrent.

14 (a) Either coil or a magnet should be in motion relative to each other.

(b) If there is a relative motion between a current carrying coil and a coil without current.

15. Refer to Theory.

16. (i) Electro chemical cells (ii) Lead accumulator (iii) D.C. Generator.

17. A.C. generator, hydropower stations, etc.

18. (c) half revolution

19. (a) A fuse of proper rating should be used to avoid damages due to short circuiting and overloading.

(b) Earthing should be provided to avoid shocks when the live wire touches the body of the appliances.

20. $P = \frac{V^2}{R}$

$$2 \times 10^3 = \frac{220 \times 220}{R} \Rightarrow R = \frac{220 \times 220}{2 \times 10^3}$$

$$I = \frac{V}{R} = \frac{220 \times 2 \times 10^3}{220 \times 220} = \frac{100}{11} = 9.09\text{A}$$

At this stage, due to very high value of current, oven will be damaged.

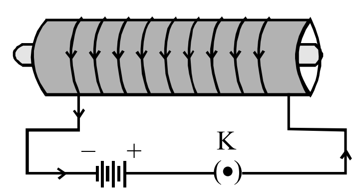
21. We can avoid overloading by not connecting too many appliances to a single socket.

Text-Book Exericse :

1. (d) The field consists of concentric circles centred on the wire according to Maxwell's Right Hand Grip Rule.
2. (c) Producing induced current in a coil due to relative motion between a magnet & the coil.
3. (a) Generator. It is also called alternator.
4. (d) AC generator has slip rings while the DC generator has a commutator.
5. (c) Increases heavily
6. (a) F, (b) T, (c) T, (d) F.
7. (i) A natural manget (ii) A current carrying conductor (iii) A solenoid.
8. A coil of many circular turns of insulated copper wire in the shape of a cylinder is called a solenoid. One end of a solenoid behaves like north pole and the other end as south pole. The field lines inside the solenoid are in the form of parallel lines. So, the field is uniform inside the solenoid.
Yes, If we bring the north pole of a bar magnet near one end of a current carrying solenoid and if it is attracted, then this end behaves as south pole & the other end is north pole.
9. We know that the force experienced by a current carrying conductor in a magnetic field is
$F = BIL \sin\theta$.
So, if θ (i.e., angle between the direction of magnetic field and current carrying conductor) is maximum i.e., 90°, then the force is maximum.
10. The magnetic field is perpendicular to the plane containing the beam of electrons and the force acting on it.
11. Refer to theory.
12. (a) Fan (b) Motor cycle
(c) Cooler (d) Air conditioner.
13. (i) When a bar magnet with its north pole facing the coil is moved towards the coil, the galvanometer shows a deflection.
(ii) When a bar magnet is moved away from the coil galvanometer again shows deflection but now in opposite direction.
(iii) When the bar magnet is stationary near the coil, no deflection in the galvanometer is observed.
14. Yes, we know that larger the current, stronger will be the magnetic field. As there is change in current in coil A, there is a decrease in the number of magnetic field lines passing through coil B and hence, due to change in the number of magnetic field lines, there is an induced current in coil B.
15. (i) Maxwell's Right Hand Thumb Rule
(ii) Fleming's Left Hand Rule
(iii) Fleming's Right Hand Rule
16. Refer to theory.
17. Electric short circuit occurs when
(i) a current of value more than its rating passes through a wire;
(ii) the live wire touches with the earth or neutral-wire;
(iii) the insulation of the wires is weak;
(iv) over load is provided in the circuit.
18. The earth wire is a wire which connects a given appliance to the earth. It is used as a safety measure especially for electric appliances having a metallic body. Whenever the live wire touches the body of the appliance, the current passes to the earth and the user doesn't suffer a severe electric shock.

Exemplar Questions :

1. In the plane of the paper itself. The axis of the compass is vertical and the field due to the conductor is also vertical. It could result in a dip of compass needle which is not possible in this case (dips result only if axis of compass is horizontal). The deflection is maximum when the conductor through A is perpendicular to the plane of paper and the field due to it is maximum in the plane of the paper.
2. (i) The current through the solenoid should be direct current.
(ii) The rod inside is made of a magnetic material such as steel.



3. *Into* the plane of paper at P and *out* of it at Q. The strength of the magnetic field is larger at the point located closer i.e., at Q.
4. (i) Yes, Alpha particles being positively charged constitutes a current in the direction of motion. (ii) No. The neutrons being electrically neutral constitute no current.
5. Direct current always flows in one direction but the alternating current reverses its direction periodically. The frequency of AC in India is 50 Hz and in each cycle it alters direction twice. Therefore AC changes direction $2 \times 50 = 100$ times in one second.
6. Current carrying loops behave like bar magnets and both have their associated lines of field. This modifies the already existing earth's magnetic field and a deflection results. Magnetic field has both direction and magnitude. Magnetic field lines emerge from N-pole and enter S-pole. The magnetic field strength is represented diagrammatically by the degree of closeness of the field lines. Field lines cannot cross each other as two values of net field at a single point cannot exist. Only one value, a unique net value, can exist. If in a given region, lines of field are shown to be parallel and equispaced, the field is understood to be uniform.

Hots Questions :

1. Direction of magnetic field inside the loop is perpendicular to the plane of paper inward and direction of magnetic field outside the loop is perpendicular to the plane of paper outward.
2. The current is in the east-west direction. Applying the right-hand thumb rule, we get that the direction of magnetic field at a point below the wire is from north to south. The direction of magnetic field at a point directly above the wire is from south to north.
3. The force experienced by a current-carrying conductor placed in a magnetic field is largest when the direction of current is at right-angles to the direction of the magnetic field.
4. (i) In electric field, there is always a force on the moving electron opposite to the direction of field. Thus the force will be zero only if field is zero.
   (ii) In magnetic field, the force acting on a moving electron is $F = q\,v\,B \sin\theta$, it is zero if $\theta = 0°$ or $180°$
   i.e., the electron is moving parallel to the direction of magnetic field.
5. It assumes circular shape with its plane normal to the field to maximize flux, since for a given perimeter, a circle encloses greater area than any other shape.
6. If electron passing through a certain region does not suffer any deflection, then we are not sure that there is no magnetic field in that region. This is due to that electron suffers no force when it moves parallel or antiparallel to magnetic field. Thus the magnetic field may exist parallel or antiparallel to the direction of motion of electron.
7. Pure iron is not used for making permanent magnets because it cannot retain their magnetism for long time and used only for electromagnet since alloys of iron and steel have strongly magnetised and have a capacity to hold it for a longer time period, they are used for permanent magnets.
   Material used for permanent magnet–ALNICO. Formation of a permanent magnet electrically. Permanent magnets can be formed by placing a hard steel rod in the strong uniform magnetic field produced by the solenoid. Steels have the quality to retain its magnetism after switch off the solenoid current.
   Permanent magnets are used in
   (i) Galvanometer
   (ii) Ammeter.
8. The strength of the magnetic field produced at the centre of a circular coil of radius r, having N turns and carrying a current, I, is given by
   $$B = \frac{\mu_0 NI}{2r} \text{ testla}$$
   Thus, the strength of a magnetic field in the coil is
   (i) inversely proportional to the radius of the loop.
   $$\left(B \propto \frac{1}{r}\right)$$
   (ii) directly proportional to the number of turns. $(B \propto N)$
   (iii) directly proportional to the current passing through it. $(B \propto I)$
9. Four times
10. (i) In figure, the current in the coil is in direction DCBA. By Fleming's left hand rule, on the arm AB, the force is outward at right angles to the plane of the coil. On the arm BC no force acts. On the arm CD, the force is inwards perpendicular to the plane of the coil. On the arm DA, no force acts.
    (ii) The force on the arms AB and CD are equal in magnitude, but opposite in direction. They form a clockwise couple. So the coil will rotate clockwise with the arm AB coming out and the arm CD going in.
    (iii) On interchanging the terminals of the battery, the coil will rotate anticlockwise.
11. Yes, our metal cars moving over a wide, closed loop of wire embedded in a road surface, change the magnetic field of the earth within the loop.
    This change in the magnetic field induces currents in the wire loops and a current pulse is produced.
    At a traffic intersection, the color of the traffic light changes as a result of these current pulses.
12. As soon as the piece of metal changes the magnetic field in the coil, voltage is induced which sounds an alarm and the security personnel detect the metal.
13. The direction of induced current will be anti-clockwise i.e. along PSRQP. This is given by Flemming's right hand rule.

3 EXERCISE

Single Option Correct :

1.	(d)	**2.**	(d)	**3.**	(d)	**4.**	(a)	**5.**	(a)
6.	(a)	**7.**	(b)	**8.**	(d)	**9.**	(c)	**10.**	(b)
11.	(b)	**12.**	(a)	**13.**	(c)	**14.**	(b)	**15.**	(c)
16.	(d)	**17.**	(a)	**18.**	(d)	**19.**	(b)	**20.**	(d)
21.	(a)	**22.**	(c)	**23.**	(b)	**24.**	(d)	**25.**	(b)
26.	(a)	**27.**	(d)	**28.**	(d)	**29.**	(c)	**30.**	(d)
31.	(c)	**32.**	(b)	**33.**	(b)	**34.**	(a)	**35.**	(b)
36.	(c)	**37.**	(d)	**38.**	(b)	**39.**	(c)	**40.**	(a)
41.	(d)	**42.**	(b)	**43.**	(c)	**44.**	(d)	**45.**	(d)
46.	(d)	**47.**	(b)	**48.**	(b)				

More Than One Option Correct :

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

Passage Based Questions :

1.	(d)	**2.**	(c)	**3.**	(c)

Assertion & Reason :

1. (b) In the case of metallic rod, the charge carries flow through whole of the cross section. Therefore, the

magnetic field exists both inside as well as outside. However magnetic field inside the rod will go no decreasing as we go towards the axis.

2. (c) From equation $F = qvB \sin\theta$. Force on moving charge will be maximum if direction of velocity of charge is perpendicular to direction of magnetic field (when $\theta = 90°$)

3. (a)

4. (a) Magnetic force is always perpendicular to the direction of motion of charged particle, i.e., work done on the charge particle moving on a circular path in magnetic field is zero.

5. (b) The wires are parallel to each other but the direction of current in it is in same direction so they attract each other. If the current in the wire is in opposite direction then wires repel each other. When the currents are in opposite directions, the magnetic forces are reversed and the wires repels each other

6. (d) When current flows through a solenoid, the currents in the various turns of the solenoid are parallel and in the same direction. Since the currents flowing through parallel wires in the same direction lead to force of attraction between them, the turns of the solenoid will also attract each other and as a result the solenoid tends to contract.

7. (c) In a conductor, the average velocity of electrons is zero. Hence no current flows through the conductor. Hence, no force acts on this conductor.

8. (b) The torque acting on a coil is given by,

$$\tau = NIAB \sin\theta$$

where θ is the angle between the plane of the coil and the direction of magnetic field. When $\theta = 90°$, then $\tau = 0$. The coil tries to orient itself in this position. Thus in equilibrium, the coil acquires a position, such that its plane makes an angle 90° with the direction of magnetic field.

9. (a) In case of the electric field of an electric dipole, the electric lines of force originate from positive charge and, end at negative charge. Since, isolated magnetic lines are closed continuous loops extending throughout the body of magnet, hence they from endless curves.

10. (c) Force acting on each pair of the opposite sides of the coil are eq.

11. (a)

Muliple Matching Question:

1. (c) $A \to r$; $B \to p$; $C \to p$; $D \to s$

The force experienced by a coil in a magnetic field is given by $F = P_m \dfrac{\partial B}{\partial r}$, where $\dfrac{\partial B}{\partial r}$ is the increment of B along magnetic dipole moment of contour. You can write the expression for magnetic field due to solenoid at a general point and then differentiate it. From this information, you can have the results. Whether the force is attractive or repulsive can also be found by using the concept of nature of poles induced on the solenoid and coil.

The force comes out to be zero at centre and as we approach it from some outside point, its value increases.

For D: The coil first rotates to allign itself in such a manner so as to link the maximum flux and then the case would be same as that of C.

Integer/Numeric Question:

1. When a charged particle is moving in a uniform magnetic field it experiences a force in a direction, perpendicular to its direction of motion. Due to which the speed of the charged particle remains unchanged and work done on it is zero, hence its kinetic energy remains same.

2. To detect the presence of the magnetic field created by the current in a circular loop at the centre, one can draw the magnetic field lines with the help of compass needle. The magnetic field lines appear as a straight line at the centre and other lines appear in the same direction without the loop.

Direction of field is given by the right hand thumb's rule.

Right hand thumb rule. Hold the wire in your right hand with your extended thumb pointing in the direction of current. Your folded fingers will indicate the direction of magnetic field around the wire.

3. $B = ?, I = 2\text{ A}, L = 3\text{ m}$

$F = 1\text{ N}$

$F = BIL$

$1 = 2 \times 3 \times B \Rightarrow \dfrac{1}{6} = B$

$B = 0.16$ Tesla

4. $r = 22\text{ cm} = 0.22\text{ m}, n = 14, I = 5\text{A}, \mu_0 = 4\pi \times 10^{-7}\text{ Tm/A}$

$$B = n \times \frac{\mu_0 I}{2r} = 14 \times \frac{4\pi \times 10^{-7} \times 5 \times 10^2}{2 \times 122}$$

$$= 14 \times 2 \times \frac{22}{7} \times \frac{10^{-5} \times 5}{22} = 20 \times 10^{-5}\text{ Tesla.}$$

5. $r = 0.05\text{ m.}, n = 500, I = 1\text{ A},$

$\mu_0 = 4\pi \times 10^{-7}\text{ Tm/A}$

$$B = \frac{\mu_0 In}{2r} = \frac{4\pi \times 10^{-7} \times 1 \times 500}{2 \times 0.05}$$

$= 6.28 \times 10^{-3}$ T.

6. $r = 0.01\text{ m.}, \mu_0 = 4\pi \times 10^{-7}\text{ Tm/A}, I = 2\text{A}$

$$B = \frac{\mu_0 I}{2\pi r} = \frac{4\pi \times 10^{-7} \times 2}{2 \times \pi \times 0.01} = 4 \times 10^{-5}\text{ T}$$

7. $\mu_0 = 4\pi \times 10^{-7}$ Tm/A; $r = 15\text{ cm} = 0.15\text{ m}$; $I = 60\text{A}$

$n = 20$ turns

$$B = \frac{n\mu_0 I}{2r} = \frac{20 \times 4\pi \times 10^{-7} \times 60}{2 \times 0.15} = 5 \times 10^{-3}\ T$$

8. $I = 5A, L = 0.04\ m, B = 0.30\ T$

$F = B \times I \times L = 0.30 \times 5 \times 0.04 = 0.06\ N$

9. $B = 4\ T,\ Q = 1.6 \times 10^{-19}\ C, V = 3.5 \times 10^{7}\ m/s$

$F = B \times Q \times V = 4 \times 1.6 \times 10^{-19} \times 3.5 \times 10^{7}$

$= 2.24 \times 10^{-11}\ N$

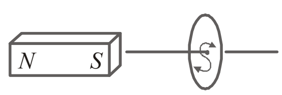
4 ADVANCED EXERCISE
BASED ON CONNECTING TOPICS

1. (b)	**2.** (a)	**3.** (a)	**4.** (c)
5. (d)	**6.** (c)	**7.** (b)	**8.** (a)
9. (a)	**10.** (b)	**11.** (c)	**12.** (c)
13. (d)	**14.** (a)	**15.** (d)	**16.** (a)
17. (c)	**18.** (d)	**19.** (b)	**20.** (c)
21. (d)	**22.** (a)	**23.** (c)	

24. (a, d)

25. (a, b, c)

26. (b, d) The near face of the loop behaves like south pole and far face as north pole. So loop will be repelled by the magnet.



27. (a, b) $\chi_m = \frac{C}{(T - T_C)}$.

28. (a) **29.** (d) **30.** (b)

31. (a) **32.** (d) **33.** (c)

34. (a)

35. (b)

36. (a) Lenz's law (that the direction of induced e.m.f. is always such as to oppose the change that cause it) is direct consequence of the law of conservation of energy.

37. (b)

38. (a) Work done by magnetic force is zero. From work-energy theorem, its speed or kinetic-energy is constant.

39. (c) **A : q, r**

The magnetic field at P due to current flowing in AB is perpendicular to the plane of paper acting vertically downward. And the magnetic field at P due to current flowing in CD is perpendicular to the plane of paper acting vertically upwards.

Therefore, q is correct.

As P is the mid point, the two magnetic fields, cancel out each other. Therefore, r is correct.

B : p

The magnetic field at P due to current in loop A is along the axial line towards right. Similarly, the magnetic field at P due to current in loop B is also along the axial line towards right.

C : q, r

The magnetic field due to current in loop A at P is equal and opposite to the magnetic field due to current in loop B at P.

D : q, s

The direction of magnetic field at P due to current in loop A is perpendicular to the plane of paper directed vertically upwards.

The direction of magnetic field at P due to current in loop B is perpendicular to the plane of paper directed vertically downward.

Since the current are in opposite direction the wires repel each other.

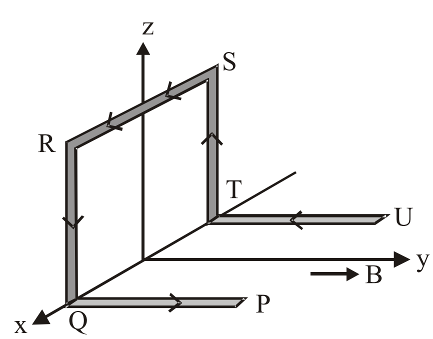
40. The magnetic field of earth at that point becomes zero, when wire produces equal and opposite field. So

$$\frac{\mu_0}{2\pi}\cdot\frac{i}{r} = B_H$$

$$\therefore \quad i = \frac{B_H r}{(\mu_0 / 2\pi)} = \frac{(39 \times 10^{-6}) \times 0.08}{2 \times 10^{-7}}$$

$\approx$ 16 A from west to east

41. If we join P to U by a straight conductor it will become a closed loop and as in case of closed loop in a uniform magnetic field,



If $\vec{F}_W$ is the force on the given network of wires and $\vec{F}'$ on the wire PU, then

$\vec{F}_W + \vec{F}' = 0$ i.e., $\vec{F}_W = -\vec{F}'$

But as $\vec{F}' = B\,I\,L \sin 90°$ along negative z-axis,

so, $\vec{F}_W = B\,I\,L$ along z-axis

42. Given : $v = 10^5\ m/s$; $e = 1.6 \times 10^{-19}\ C$;

$m = 9.1 \times 10^{-31}\ kg$; $B = 0.019\ G = 0.019 \times 10^{-4}\ T$

$$r = \frac{m\,v}{B\,e} = \frac{9.1\times10^{-31}\times10^{5}}{0.019\times10^{-4}\times1.6\times10^{-19}} = 0.299\,\text{m}$$

43. Given : e = 10 V and $\frac{dI}{dt} = \frac{1-0.5}{0.2} = \frac{0.5}{0.2} = 2.5\ \text{A/s}$

Self inductance of coil $L = \frac{e}{dI/dt} = \frac{10}{2.5} = 4\ \text{H}$

$\because\ e = L\frac{dI}{dt}$ (considering magnitude only)

44. Given : $M = 0.75$ H and $\frac{dI}{dt} = \frac{0.5-0}{0.01} = 50\ \text{A/s}$

$\therefore$ Average induced e.m.f. in secondary coil

$$e = M\frac{dI}{dt} = 0.75\times50 = 37.5\ \text{V}$$

45. $= 220\text{V};\ r = 10\Omega$

$R' = 10 + 100\Omega = 110\Omega$

$$I = \frac{V}{R'} = \frac{220}{110} = 2A$$

$P = I^2R = 4\times100 = 400\ W$

Chapter 5

SOURCES OF ENERGY

INTRODUCTION

We use energy to do work. Energy lights our cities. Energy powers our vehicles, trains, planes and rockets. Energy warms our homes, cooks our food, plays our music, gives us pictures on television. Energy powers machinery in factories and tractors on a farm. Energy from the sun gives us light during the day. It dries our clothes when they're hanging outside on a clothes line. It helps plants grow. Energy stored in plants is eaten by animals, giving them energy. And predator animals eat their prey, which gives the predator animal energy. Everything we do is connected to energy in one form or another. Energy is defined as "the ability to do work."

When we eat, our bodies transform the energy stored in the food into energy to do work. When we run or walk, we "burn" food energy in our bodies. When we think or read or write, we are also doing work (everyday meaning not scientific meaning). Cars, planes, light bulbs, boats and machinery also transform energy into work. Work means moving something, lifting something, warming something, lighting something. All these are a few of the various types of work. But where does energy come from? There are many sources of energy. Energy is an important part of our daily lives.

Various forms of energy includes: Electricity, Biomass energy - energy from plants, Geothermal energy, Fossil Fuels - Coal, Oil and Natural gas, Hydro power and Ocean energy, Nuclear energy, Solar energy, Wind energy.

All forms of energy are stored in different ways, in the energy sources that we use everyday. These sources are divided into two groups -- renewable (an energy source that can be replenished in a short period of time) and non-renewable (an energy source that we are using up and cannot recreate in a short period of time). Renewable and non-renewable energy sources can be used to produce secondary energy sources including electricity.

GOOD SOURCE OF ENERGY

A good source of energy would be one which would do a large amount of work per unit volume or mass, be easily accessible, be easy to store and transport, and perhaps most importantly, be economical. **so evaluation criteria for good source of energy are:** *Capital Costs, Operating costs, efficiency, Is it renewable? Energy storage requirements, Pollution, Environmental modification, Levelized cost to the consumer, Feasibility on large scale, unit Capacity .*

CONVENTIONAL SOURCES OF ENERGY

Fossil Fuels

Fossil fuels are hydrocarbon based natural resources that were formed over 300 hundred millions of years ago by the fossilization of prehistoric plants and animals. There are three major forms of fossil fuels: coal, oil and natural gas. We have learned to harness the energy released from these fossil fuels during combustion in order to meet our energy needs. Fossil fuels are a common source of energy we use everyday. They are used to generate the electricity that runs our household appliances, fuel the motors of our cars, and heat our homes. Fossil fuels are currently essential to providing the energy needs of our everyday lives.

Although the supplies of these fossil fuels are vast, they are not unlimited. Fossil fuels are depleting at an alarming rate. They are a non-renewable resource and we are consuming vast quantities of them every day. Varying estimates project a complete depletion of oil and natural gas within anywhere from 40-100 years. Coal is the most abundant of the three and will last for about another 230 years. It is very likely that within our life times that one of these fossil fuels, if not more, will be completely consumed from the planet. And more important, the earth's atmosphere and biosphere may not survive the environmental impact of burning such enormous amounts of these fuels. Global warming is directly associated with the increase in greenhouse gases produced from the burning of fossil fuels. Carbon stored over millions of years is being released in a matter of decades, disrupting the earth's carbon cycle in unpredictable ways.

But fossil fuels are not the only source of energy, and burning fuel is not the only way to produce heat and motion. Renewable energy offers us a better way. Some energy sources are "renewable" because they are naturally replenished, because they can be managed so that they last forever, or because their supply is so enormous that they can never be meaningfully depleted by humans. Moreover, renewable energy sources have much smaller environmental impacts than fossil and nuclear fuels.

Thermal Power Plant

A thermal power station comprises all of the equipment and systems required to produce electricity by using a steam generating boiler fired with fossil fuels or biofuels to drive an electrical generator. Such power stations are most usually constructed on a very large scale and designed for continuous operation.

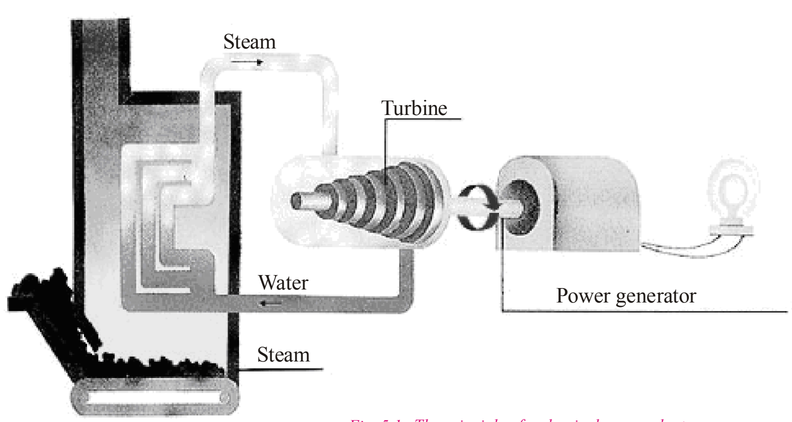


Fig. 5.1 The principle of aclassical power plant

Electricity generation in thermal power plants includes firing of coal, gas or mazout. Steam is produced in a boiler, and it drives a turbine connected to a generator. Heat energy is converted to electric energy within the so-called steam cycle.

A thermal plant comprises several separate production units with specific size and power.

A conventional power plant consists of a boiler room, interposed machine room, machine room, electric power output, and auxiliary operations (coal loading, water treatment, water management, back fuel cycle, etc.). The following types of thermal power plants exist: condensating, whose main focus is generation of electricity, thermal plants whose main focus is combined generation of electricity and heat.

In a conventional condensating type thermal power plant, the electricity generation part is dominated by arrangement in production units. Every production unit of the power plant represents a separate generation entity a separate power plant. By the method of combustion, solid fuel firing boilers are classified into grate, granulation, fusion, and fluidized-bed type. Boilers firing solid and gas fuels are in addition to the above mentioned boilers.

Every power plant unit may be operated independently. The principle of operation is quite simple. Stockpile coal is moved by a bulldozer into an underground bunker, wherefrom it is taken by a coaling belt into a coal holder located at every boiler. The coal is gradually dried and ground to powder that is subsequently fired in the boiler. Pipe or membrane type evaporators are located in the boiler walls; there, water turns into steam and the steam generated (of a high temperature and pressure) is led to steam cylinder, wherefrom it is led through pre-heaters and postheaters via steam distribution pipes to turbine blades. The turbine is connected to a generator.

Turbine and electric generator comprises a single train – turbogenerator. In the turbogenerator, heat energy is converted into electric energy. Electric energy thus produced is led through a system of transformers and distribution grid to end-consumers. Having delivered its energy to turbine blades, the steam condensates in heat exchanger – condenser. Upon passing the turbine, the steam temperature and pressure get reduced. The steam changes its state and turns into water called condensate. Large quantities of cooling energy are needed for steam to condensate. Surface water from a stream or a reservoir is used for cooling. If there is a plenty of cooling water, flow-through system of cooling is used; circulation system of cooling with water being cooled in cooling towers is used for places with insufficient supply of cooling water.

On their way to the stack, flue gases produced during the firing of coal heat water in economizer, which is a heat exchanger for combustion gas. Cooled stack gases then pass through electrostatic filters where ash is caught, and continue to the stack.

To reduce nitrogen and sulfur oxides, desulfurization and denitrification equipment are installed to conventional boilers. For fluidized-bed boilers, desulfurization and denitrification is resolved directly by the boiler technology.

You may have heard about NTPC largest thermal power generating company of India.

In 1995, India had an installed electrical generating capacity of 81 gigawatts (GW), of which 73 per cent was thermal. This is the world's sixth largest capacity and equal to that of France and the United Kingdom. India's power sector has grown at an average annual rate of 8.8 per cent since 1950, when installed capacity was only 2.3 GW. About 85 per cent of the country was electrified in 1995. Despite the dramatic increase in power generation capabilities, India has been unable to keep up with its domestic demand for electricity. India's electricity is generated overwhelmingly by coal (70 per cent). Hydroelectricity ranks a distant second (about 25 per cent), followed by natural gas, nuclear power, oil, and renewables.

Hydro Power Plants

When it rains in hills and mountains, the water becomes streams and rivers that run down to the ocean. The moving or falling water can be used to do work. Energy, you'll remember is the ability to do work. So moving water, which has kinetic energy, can be used to make electricity.

For hundreds of years, moving water was used to turn wooden wheels that were attached to grinding wheels to grind (or mill) flour or corn. These were called grist mills or water mills.

Hydro means water. Hydro-electric means making electricity from water power. In fact, humans have been using the energy in moving water for thousands of years. Today hydroelectric power is the largest source of renewable power worldwide. A quarter of our energy requirement in India is met by hydro power plants.

Hydroelectric power uses the kinetic energy of moving water to make electricity. Dams can be built to stop the flow of a river. Water behind a dam often forms a reservoir.

The water behind the dam flows through the intake and into a pipe called a penstock.

The *principle of the operation of hydroelectric power plants is conversion of mechanical energy into electric energy*. Water stream passes stable turbine vanes and thus directed water stream hits water turbine blades of the turbine runner curved in an opposite direction; in this way, the blades are turned, and receive mechanical energy from water. Mechanical energy of water is converted into mechanical energy of the shaft, and subsequently to electric energy in electric generators. Electric generators of hydroelectric power plants convert mechanical energy to electric energy with a high efficiency. In synchronous generators, electric energy is generated by inducing rotating magnetic field of the rotor into stable generator stator coil. To generate magnetic field of the rotor, excitation direct current is needed generated in generator exciter.

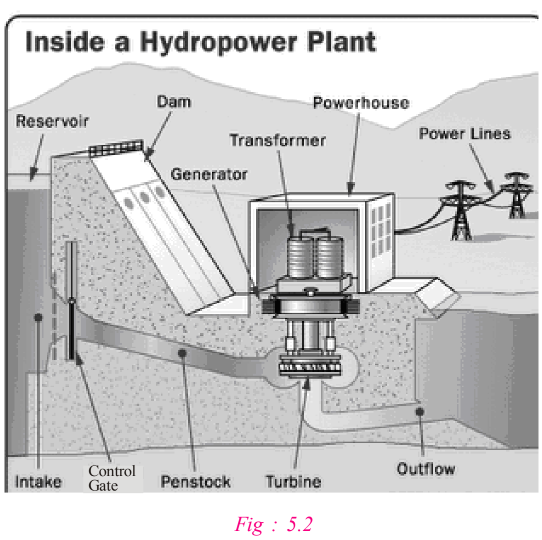


Fig : 5.2

Hydroelectric generation can also work without dams, in a process known as diversion, or run-of-the-river. Portions of water from fast-flowing rivers, often at or near waterfalls, can be diverted through a penstock to a turbine set in the river or off to the side. The generating stations at Niagara Falls are an example of diversion hydropower. Another run-of-the-river design uses a traditional water wheel on a floating platform to capture the kinetic force of the moving river. While this approach is inexpensive and easy to implement, it doesn't produce much power. The entire Amazon River, if harnessed this way, would produce only 650 MW of power.

Another type of hydropower, though not a true energy source, is pumped storage. In a pumped storage plant, water is pumped from a lower reservoir to a higher reservoir during off-peak times, using electricity generated from other types of energy sources. When the power is needed, it is released back into the lower reservoir through turbines. Inevitably, some power is lost, but pumped storage systems can be up to 80 per cent efficient. Future increases in pumped storage capacity could result from the integration of hydropower and wind power technologies. Researchers believe that hydropower may be able to act as a battery for wind power by storing water during high wind periods.

Although an inexpensive and nonpolluting energy resource, the environmental damage caused hydropower can be serious. The most obvious effect is that fish are blocked from moving up and down the river, but there are many more problems.

When a dam is constructed, a river habitat is replaced by a lake habitat. While this may not sound so bad – fish and birds like lakes, too it can cause a number of environmental problems. Dams can create large reservoirs submerging what used to be dry land, producing many problems. Population density is typically higher along rivers, leading to mass dislocation of urban centers. Opposition to the construction of Tehri Dam on the river Ganga and Sardar Sarovar project on the river Narmada are due to such problems.

Wildlife habitats destroyed by reservoirs can be especially valuable. Another problem can occur when the land area behind the dam is flooded without proper preparation. Later, as the plants and trees that were submerged began to rot, they reduced the oxygen content of the water, killing off the plants and fish in the water. Moreover, the rotting plants gave off large quantities of methane, a powerful global warming gas.

Impoundments used for hydropower can cause many other effects on water quality and aquatic life. Rivers and lakes can be filled with sediment from erosion. Water falling over spillways can force air bubbles into the water, which can be absorbed into fish tissue, ultimately killing the fish. By slowing down rivers, the water can become stratified, with warm water on top and cold water on the bottom. Since the cold water is not exposed to the surface, it loses its oxygen and becomes uninhabitable for fish.

The risk of a dam breaking should also not be ignored. The great Johnstown flood in Pennsylvania was the result of a dam break (although not a hydroelectric dam); 2,000 people were killed. In northern India and Nepal, in the Himalayas, huge hydroelectric projects are planned that would create large reservoirs in a geographically unstable region. Frequent earthquakes make the dam a risky venture for heavily populated areas downstream. This is compounded by the fear that large, heavy reservoirs would put additional pressure on the plates in the region, causing even more earthquakes. Finally, breakage could also result from war or terrorism, as dams have been considered potential military targets in the past. The environmental and social effects of hydropower can be immense. But while hydropower has its problems, it can still be a safe and sustainable source of electricity if proper measures are taken. By upgrading and improving the equipment at plants, by increasing fish-friendly efforts at dams, and by improving run-of-the-river turbine technology, it may be possible to reduce the environmental effects of hydropower. Nonetheless, remediation may be impossible at some sites, and wild rivers should be unshackled.

It is also important to compare the environmental effects of hydropower with alternatives. The damage to aquatic habitat from dams may be significant, but acid rain, nitrogen deposition, and thermal pollution from coal plants also lead to aquatic damage, as well as to air pollution and global warming.

IMPROVEMENTS IN TECHNOLOGY FOR USING CONVENTIONAL SOURCES OF ENERGY

Bio-Mass

Biomass is matter usually thought of as garbage. Some of it is just stuff lying around–dead trees, tree branches, yard clippings, left-over crops, wood chips and bark and sawdust from lumber mills. It can even include used tires and livestock manure.

Your trash, paper products that cannot be recycled into other paper products, and other household waste are normally sent to the dump. Your trash contains some types of biomass that can be reused. Recycling biomass for fuel and other uses cuts down on the need for "landfills" to hold garbage.

This stuff nobody seems to want can be used to produce electricity, heat, compost material or fuels. Composting material is decayed plant or food products mixed together in a compost pile and spread to help plants grow.

A similar thing can be done at animal feed lots. In places where lots of animals are raised, the animals - like cattle, cows and even chickens-produce manure. When manure decomposes, it also gives off methane gas similar to garbage. This gas can be burned right at the farm to make energy to run the farm.

Biomass is a renewable energy source because the energy it contains comes from the sun. Through the process of photosynthesis, chlorophyll in plants captures the sun's energy by converting carbon dioxide from the air and water from the ground into carbohydrates, complex compounds composed of carbon, hydrogen, and oxygen. When these carbohydrates are burned, they turn back into carbon dioxide and water and release the sun's energy they contain. In this way, biomass functions as a sort of natural battery for storing solar energy. As long as biomass is produced sustainably—with only as much used as is grown the battery will last indefinitely.

A number of noncombustion methods are available for converting biomass to energy. These processes convert raw biomass into a variety of gaseous, liquid, or solid fuels that can then be used directly in a power plant for energy generation. The carbohydrates in biomass, which are comprised of oxygen, carbon, and hydrogen, can be broken down into a variety of chemicals, some of which are useful fuels. This conversion can be done in three ways:

(1) Thermochemical : When plant matter is heated but not burned, it breaks down into various gases, liquids, and solids. These products can then be further processed and refined into useful fuels such as methane and alcohol. Biomass gasifiers capture methane released from the plants and burn it in a gas turbine to produce electricity. Another approach is to take these fuels and run them through fuel cells, converting the hydrogen-rich fuels into electricity and water, with few or no emissions.

(2) Biochemical : Bacteria, yeasts, and enzymes also break down carbohydrates. Fermentation, the process used to make wine, changes biomass liquids into alcohol, a combustible fuel. A similar process is used to turn corn into grain alcohol or ethanol, which is mixed with gasoline to make gasohol. Also, when bacteria break down biomass, methane and carbon dioxide are produced. This methane can be captured, in sewage treatment plants and landfills, for example, and burned for heat and power.

(3) Chemical : Biomass oils, like soyabean and canola oil, can be chemically converted into a liquid fuel similar to diesel fuel, and into gasoline additives. Cooking oil from restaurants, for example, has been used as a source to make "biodiesel" for trucks. (A better way to produce biodiesel is to use algae as a source of oils.)

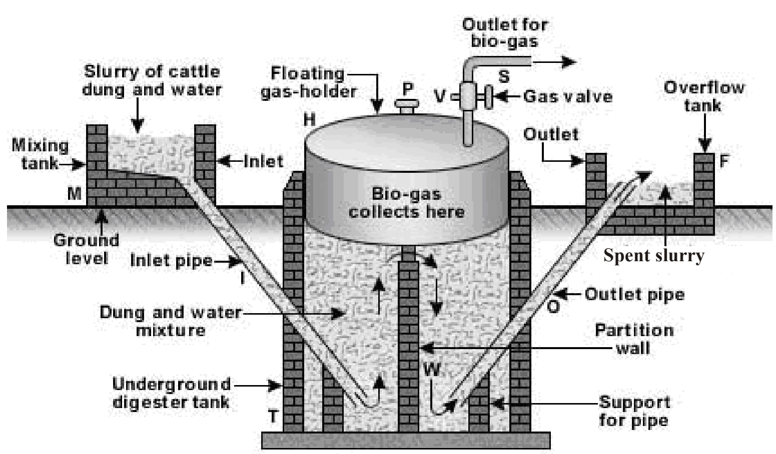
Bio-gas

Bio-gas is made from organic waste matter after it is decomposed. The decomposition breaks down the organic matter, releasing various gases. The main gases released are methane, carbon dioxide, hydrogen and hydrogen sulphide. Bacteria carry out the decomposition or fermentation. The conditions for creating bio gas has to be anaerobic that is without any air and in the presence of water. The organic waste matter is generally animal or cattle dung, plant wastes, etc. These waste products contain carbohydrates, proteins and fat material that are broken down by bacteria. The waste matter is soaked in water to give the bacteria a proper medium to grow. Absence of air or oxygen is important for decomposition because bacteria then take oxygen from the waste material itself and in the process break them down.

There are two types of bio gas plants that are used in India. These plants mainly use cattle dung called "gobar" and are hence called gobar gas plant. Generally a slurry is made from cattle dung and water, which forms the starting material for these plants. The **two types of bio-gas plants** are : (1) Floating gas-holder type (2) Fixed dome type

Floating gas holder type of bio-gas plant :

The diagram below shows the details of a floating gas holder type of bio gas plant.



Floating gas-holder type bio-gas plant.

Fig : 5.3

A well is made out of concrete. This is called the digester tank T. It is divided into two parts. One side has the inlet, from where slurry is fed to the tank. The tank has a cylindrical dome H made of stainless steel that floats on the slurry and collects the gas generated. Hence the name given to this type of plant is floating gas holder type of bio gas plant. The slurry is made to ferment for about 50 days. As more gas is made by the bacterial fermentation, the pressure inside H increases. The gas can be taken out through outlet pipe V. The decomposed matter expands and overflows into the next chamber in tank T. This is then removed by the outlet pipe to the overflow tank and is used as manure for cultivation purposes.

Fixed dome type of bio-gas plant :

The diagram below shows the details of a fixed dome type of bio gas plant.

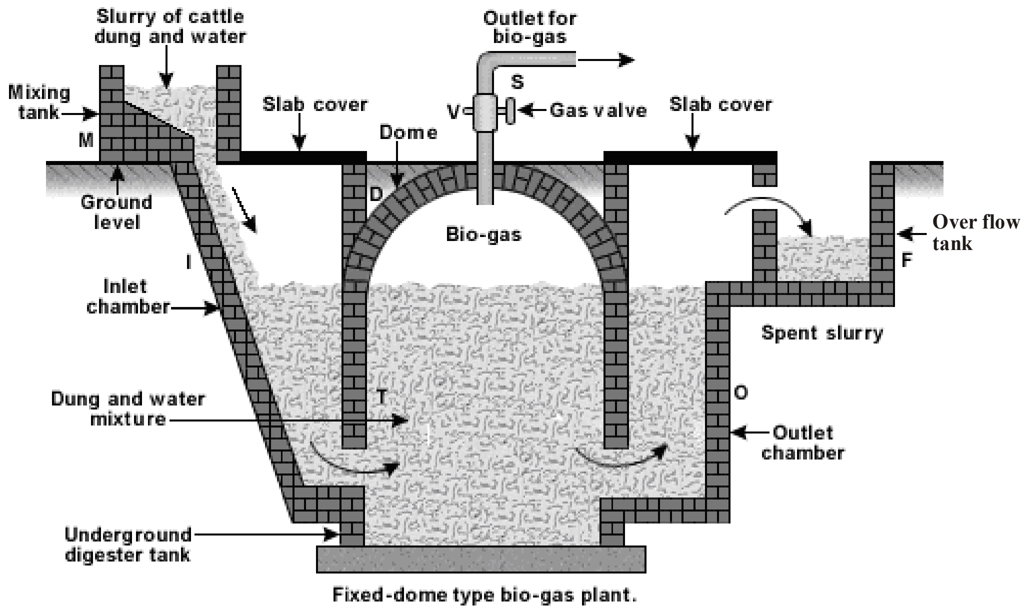


Fig : 5.4

A well and a dome are made out of concrete. This is called the digester tank T. The dome is fixed and hence the name given to this type of plant is fixed dome type of bio gas plant. The function of the plant is similar to the floating holder type bio gas plant. The used slurry expands and overflows into the overflow tank F.

Bio gas is used as cooking fuel as it contains up to 75% methane and burns without smoke, has high calorific value, can be piped into kitchens directly from a plant and is cheaper in cost.

Bio gas can be used to run electric engines such as pumps, as they cause less air pollution.

Bio gas can be used for street lighting as they do not cause any smoke and the illumination obtained can be made to be quite adequate.

Wind Energy

Along with sun, it was the air, which showed man its power. Even before the solar energy, it was the wind energy that man used for his work. Initially, it was used in two main ways; to drive wind mills on land and to drive sailing vessels at sea. The first use of windmills were to grind foods grains and to run pumps to irrigate. Farmers have been using wind energy for many years to pump water from wells using windmills. Now with the advancement of science and technology, we have windmills generating electricity. Naturally, now this energy can be used for many more works.

Fig : 5.5(a) Wind mill

Fig : 5.5(b) Wind farm

Wind is simple air in motion. It is caused by the uneven heating of the earth's surface by the sun. Since the earth's surface is made of very different types of land and water, it absorbs the sun's heat at different rates.

During the day, the air above the land heats up more quickly than the air over water. The warm air over the land expands and rises, and the heavier, cooler air rushes in to take its place, creating winds. At night, the winds are reversed because the air cools more rapidly over land than over water.

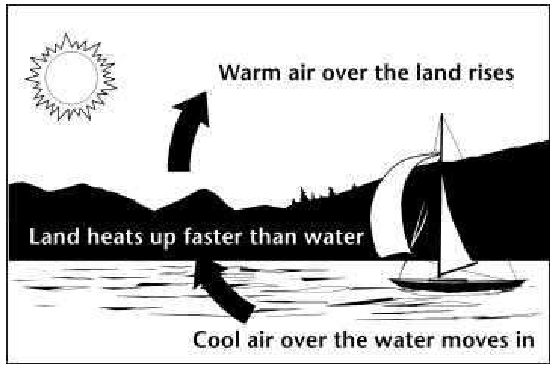


Fig : 5.6

In the same way, the large atmospheric winds that circle the earth are created because the land near the earth's equator is heated more by the sun than the land near the North and South Poles.

What makes the wind blow?

Wind is the response of the atmosphere to uneven heating conditions. This creates pressure differences in the atmosphere causing the wind to blow from regions of high atmospheric pressure to low atmospheric pressure. The larger the pressure difference the greater the wind velocity.

Air pressure represents the amount of atmosphere that is pressing down on the surface of the earth at some point, as shown here:

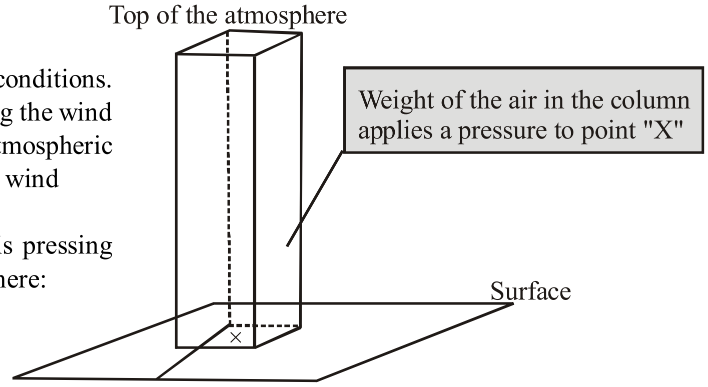


Fig. 5.7

Pressure differences yield wind (bulk motion of the air).

Wind can be used to do work. The kinetic energy of the wind can be changed into other forms of energy, either mechanical energy or electrical energy. Infact wind energy is the fastest growing source of electricity in the world.

Harnessing the wind is one of the cleanest, most sustainable ways to generate electricity. Wind power produces no toxic emissions and none of the heat trapping emissions that contribute to global warming. This, and the fact that wind power is one of the most abundant and increasingly cost-competitive energy resources, makes it a viable alternative to the fossil fuels that harm our health and threaten the environment.

Blowing wind spins the blades on a wind turbine – just like a large toy pinwheel. This device is called a wind turbine and not a windmill. A windmill grinds or mills grain, or is used to pump water.

The blades of the turbine are attached to a hub that is mounted on a turning shaft. The shaft goes through a gear transmission box where the turning speed is increased. The transmission is attached to a high speed shaft which turns a generator that makes electricity. If the wind gets too high, the turbine has a brake that will keep the blades from turning too fast and being damaged.

In order for a wind turbine to work efficiently, wind speeds usually must be above 12 to 14 miles per hour. Wind has to be this speed to turn the turbines fast enough to generate electricity. The turbines usually produce about 50 to 300 kilowatts of electricity each. A kilowatt is 1,000 watts (kilo means 1,000). You can light ten 100 watt light bulbs with 1,000 watts. So, a 300 kilowatt (300,000 watts) wind turbine could light up 3,000 light bulbs that use 100 watts.

Once electricity is made by the turbine, the electricity from the entire wind farm is collected together and sent through a transformer. There the voltage is increase to send it long distances over high power lines.

The wind resource–how fast it blows, how often, and when–plays a significant role in its power generation cost. The power output from a wind turbine rises as a cube of wind speed. In other words, if wind speed doubles, the power output increases eight times. Therefore, higher-speed winds are more easily and inexpensively captured.

Wind speeds are divided into seven classes–with class one being the lowest, and class seven being the highest. A wind resource assessment evaluates the average wind speeds above a section of land (usually 50 meters high), and assigns that area a wind class. Wind turbines operate over a limited range of wind speeds. If the wind is too slow, they won't be able to turn, and if too fast, they shut down to avoid being damaged. Wind speeds in classes three (6.7 – 7.4 meters per second (m/s)) and above are typically needed to economically generate power. Ideally, a wind turbine should be matched to the speed and frequency of the resource to maximize power production.

The more the wind blows, the more power will be produced by wind turbines. But, of course, the wind does not blow consistently all the time. The term used to describe this is "capacity factor," which is simply the amount of power a turbine actually produces over a period of time divided by the amount of power it could have produced if it had run at its full rated capacity over that time period.

A more precise measurement of output is the "specific yield." This measures the annual energy output per square meter of area swept by the turbine blades as they rotate. Overall, wind turbines capture between 20 and 40 percent of the energy in the wind. So at a site with average wind speeds of seven m/s, a typical turbine will produce about 1,100 kilowatt-hours (kWh) per square meter of area per year. If the turbine has blades that are 40 meters long, for a total swept area of 5,029 square meters, the power output will be about 5.5 million kWh for the year. An increase in blade length, which in turn increases the swept area, can have a significant effect on the amount of power output from a wind turbine.

THE MECHANICS OF WIND TURBINES

Modern electric wind turbines come in a few different styles and many different sizes, depending on their use. The most common style, large or small, is the "horizontal axis design" (with the axis of the blades horizontal to the ground). On this turbine, two or three blades spin upwind of the tower that it sits on.

Small wind turbines are generally used for providing power off the grid, ranging from very small, 250-watt turbines designed for charging up batteries on a sailboat, to 50-kilowatt turbines that power dairy farms and remote villages. Like old farm windmills, these small wind urbines have tail fans that keep them oriented into the wind.

Large wind turbines, most often used by utilities to provide power to a grid, range from 250 kilowatts up to the enormous 3.5 to 5 MW machines that are being used offshore. Today, the average land-based wind turbines have a capacity of 1.5 MW. Large turbines sit on towers that can be anywhere from 50 to 100 meters tall, and have blades that range from 30 to 50 meters long. Utility-scale turbines are usually placed in groups or rows to take advantage of prime windy spots. Wind "farms" like these can consist of a few or hundreds of turbines, providing enough power for tens of thousands of homes.

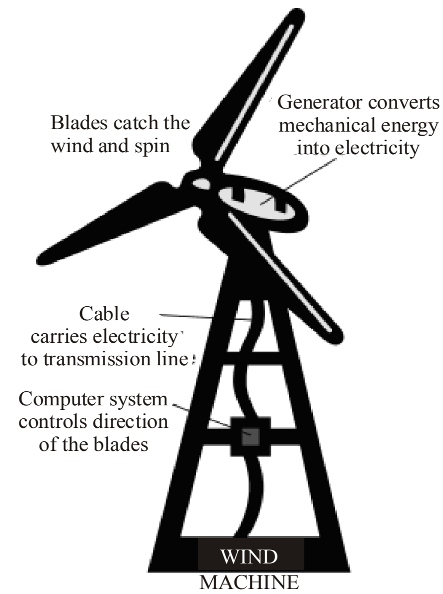


Fig : 5.8

From the outside, horizontal axis wind turbines consist of three big parts: the tower, the blades, and a box behind the blades, called the nacelle. Inside the nacelle is where most of the action takes place, where motion is turned into electricity. Large turbines don't have tail fans; instead they have hydraulic controls that orient the blades into the wind.

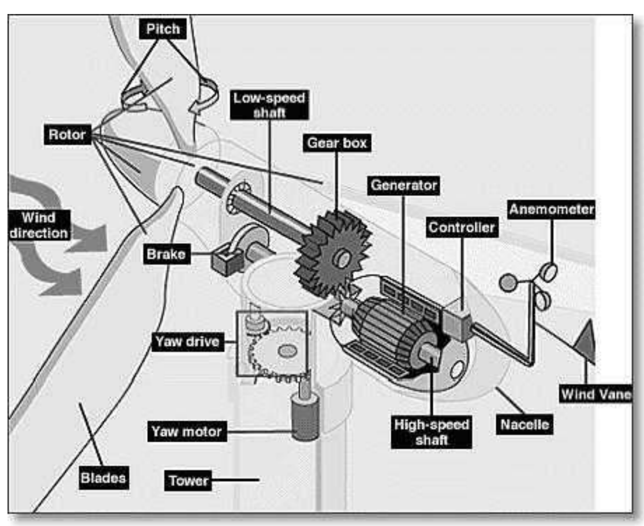


Fig : 5.9

In the most typical design, the blades are attached to an axle that runs into a gearbox. The gearbox, or transmission, steps up the speed of the rotation, from about 50 rpm up to 1,800 rpm. The faster spinning shaft spins inside the generator, producing AC electricity. Electricity must be produced at just the right frequency and voltage to be compatible with a utility grid. Since the wind speed varies, the speed of the generator could vary, producing fluctuations in the electricity. One solution to this problem is to have constant speed turbines, where the blades adjust, by turning slightly to the side, to slow down when wind speeds gust. Another solution is to use variable-speed turbines, where the blades and generator change speeds with the wind, and sophisticated power controls fix the fluctuations of the electrical output. A third approach is to use low-speed generators. An advantage that variable-speed turbines have over constant-speed turbines is that they can operate in a wider range of wind speeds. All turbines have upper and lower limits to the wind speed they can handle: if the wind is too slow, there's not enough power to turn the blades; if it's too fast, there's the danger of damage to the equipment. The "cut in" and "cut out" speeds of turbines can affect the amount of time the turbines operate and thus their power output.

Denmark is called the country of 'winds'. More than 25% of their electricity needs are generated through a vast network of windmills. In terms of total output, Germany is the leader, while India's ranked fifth in harnessing wind energy for the production of electricity. It is estimated that nearly 45,000 MW of electrical power can be generated if India's wind potential is fully exploited. The largest wind energy farm has been established near Kanyakumari in Tamil Nadu and it generates 380 MW of electricity.

The world's largest wind farm, the Horse Hollow Wind Energy Center in Texas, has 421 wind turbines that generate enough electricity to power 230,000 homes per year.

ALTERNATIVE OR NON-CONVENTIONAL SOURCES OF ENERGY

Solar Energy

The energy obtained from the sun is called solar energy. The inner temperature of the sun is very high (10^7k). At this high temperature the nucleus of lightest gas hydrogen atoms fuse to convert into heavy nucleus of helium. A lot of energy is released in this nuclear reaction. Sun is the biggest source of energy. Energy of the sun reaching every year on earth is about 1.6×10^8 KWH (Kilo watt hour). Value of energy used by all the living beings on the earth is 7×10^{13} KWH per year. It is clear that every year energy received from the sun is 2000 times more than its annual consumption. Man has been using solar energy in making salt from the sea water, drying of clothes, heating water and in form of light. In the present technological era possibilities of more broad based utilisation of solar energy are bring explored. Solar energy is tapped for heat and electricity generation. Solar energy is used in solar cooker, solar heater and solar cells.

We know today, that the sun is simply our nearest star. Without it, life would not exist on our planet. We use the sun's energy every day in many different ways.

When we hang laundry outside to dry in the sun, we are using the sun's heat to do work drying our clothes.

Plants use the sun's light to make food. Animals eat plants for food, decaying plants hundreds of millions of years ago produced the coal, oil and natural gas that we use today. So, fossil fuels is actually sunlight stored millions and millions of years ago.

Indirectly, the sun or other stars are responsible for all our energy. Even nuclear energy comes from a star because the uranium atoms used in nuclear energy were created in the fury of a nova – a star exploding.

Solar energy is one the most resourceful sources of energy for the future. One of the reasons for this is that the total energy we receive each year from the sun is around 35,000 times the total energy used by man. However, about 1/3 of this energy is either absorbed by the outer atmosphere or reflected back into space (a process called albedo).

Solar power, or energy from the Sun, is a free, abundant, and nonpolluting source of energy. This vast, clean energy resource represents a viable alternative to the fossil fuels that currently pollute our air and water, threaten our public health, and contribute to global warming.

It is estimated that during a year India receives the energy equivalent to more than 5,000 trillion kWh. Under clear (cloudless) sky conditions, the daily average varies from 4 to 7 kWh/m^2.

The solar energy per unit time reaching unit area at outer edge of the earth's atmosphere exposed perpendicularly to the rays of the Sun at the average distance between the Sun and earth is known as the solar constant. It is estimated to be approximately 1.4 kJ per second per square metre or 1.4 kW/m^2.

Solar energy can be used to heat buildings and water and to produce electricity. However, the Sun does not always shine, and the process of collecting solar energy and storing it for use at night and on cloudy days is difficult and expensive.

Solar energy systems can be either passive or active. In a passive solar heating system, a building captures and stores the Sun's heat because of the way it is designed, the materials it is made of, or the heat-absorbing structures it possesses. An example of a passive system is a building with large windows facing south (that allow sunlight to enter) and with thick walls that store heat and release it at night.

Active solar energy systems use pumps or fans to circulate heat obtained by solar collectors. A solar collector is a device that absorbs the energy of the Sun and converts it to heat for heating buildings and water. Flat-plate collectors are mounted to the roofs of buildings and used for space heating. They are made of a heat-absorbing plate, such as aluminum or copper, covered by glass or plastic. Water or air circulating in the collector absorbs heat from the plate and is carried to a heat storage tank. The stored heat is circulated or blown over cold rooms using pumps or fans. A conventional heating system is used as a backup when solar heat is not available. Solar heating of water is accomplished using a collector, a hot water storage tank, and a pump to circulate water.

Solar power plants using energy from the Sun to produce steam for driving turbines to generate electricity could potentially replace fuel-driven power plants, producing energy without any environmental hazards.

Solar Cells

Solar cell is such a device which converts solar energy into electric energy. Solar cells are also known as photovoltaic cell (PV cell) because it works on the principle of photo-voltaic effect.

Solar cells can be found on many small appliances, like calculators, and even on spacecraft.. They are made of silicon, a special type of melted sand. Silicon is abundant in nature but availability of the special grade silicon for making solar cells is limited.

When sunlight strikes the solar cell, electrons are knocked loose. They move toward the treated front surface. An electron imbalance is created between the front and back. When the two surfaces are joined by a connector, like a wire, a current of electricity occurs between the negative and positive sides.

These individual solar cells are arranged together in a PV module and the modules are grouped together in an array.

The electrical energy from solar cells can then be used directly. It can be used in a home for lights and appliances. It can be used in a business. Solar energy can be stored in batteries to light a roadside billboard at night. Or the energy can be stored in a battery for an emergency roadside cellular telephone when no telephone wires are around.

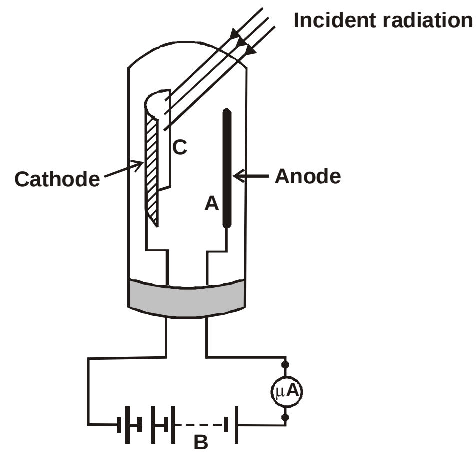


Fig : 5.10

Some experimental cars also use PV cells. They convert sunlight directly into energy to power electric motors on the car.

The principal advantages associated with solar cells are that they have no moving parts, require little maintenance and work quite satisfactorily without the use of any focussing device. Another advantage is that they can be set up in remote and inaccessible hamlets or very sparsely inhabited areas in which laying of a power transmission line may be expensive and not commercially viable. Artificial satellites and space probes like Mars orbiters use solar cells as the main source of energy. Radio or wireless transmission systems or TV relay stations in remote locations use solar cell panels.

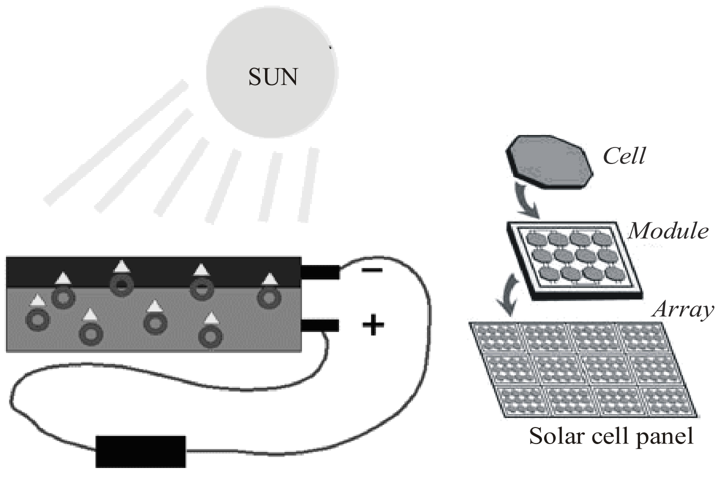


Fig : 5.11

Applications of Photo electric Cells :

1. In television cameras for telecasting scenes and photo telegraphy.
2. In reproduction of sound in motion pictures.
3. To switch on and off the street lights automatically.
4. To obtain electric energy from sun lightduring space travel.
5. To control temperature in furnaces and chemical reactions.
6. In fire and burglar's alarm, to open and close the doors automatically and in counting devices.
7. To compare illuminating power of two sources.
8. To detect opacity of solids, defects in materials, etc.

Solar Cooker

A solar cooker is a device that uses the energy in sunlight to generate sufficient temperatures to be able to cook food. Solar cookers can be used to perform most cooking tasks, such as baking cakes, roasting meat and vegetables, boiling soups, etc. The principle of using the sun to cook food is not a new concept. Swiss naturalist Horace de Saussure was known to have been experimenting with solar cookers as early as 1767. Three basic solar cooker designs exist:

- Parabolic Reflector • Box Cookers • Panel Cookers

Parabolic Reflectors

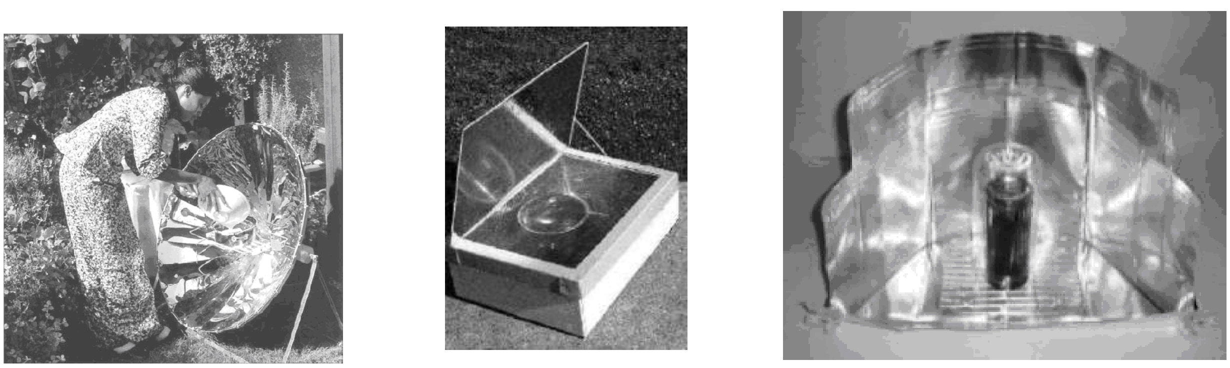
Two types of parabolic reflectors are available: Trough and dish. Parabolic cookers focus the light from the sun at or along a focal axis, Dish cookers focus the sun onto one point and cook in a similar way to single hotplates whilst trough designs are similar to rotisseries and are best used for cooking long thin foods such as sausages.

Box Cookers

As higher temperatures are often required for the cooking of food than would normally be obtained with flat plate collectors used in water heating, box cookers usually have reflectors to increase the amount of radiation that enters the collector, as shown in Figure.

Panel Cookers

A relatively new style of solar cooker, a panel cooker consists of a number of flat reflection panels that direct light onto a container to be cooked.To retain the heat, the cooking dish is placed within a plastic bag or under a glass bowl.



(a) Parabolic reflector *(b) A simple solar box cooker.* *(c) Panel cooker*

Fig. 5.12

ENERGY FROM THE SEA

Tidal Energy

(Extracts energy from the kinetic energy of the earth-moon-sun system)

Tide arise due to the gravitational pull of mainly the moon on the spinning earth. The tide moves a huge amount of water twice each day, and harnessing it could provide a great deal of energy. Although the energy supply is reliable and plentiful, converting it into useful electrical power is not easy.

Tidal energy has been used since about the 11th Century, when small dams were built along ocean estuaries and small streams. The tidal water behind these dams was used to turn water wheels to mill grains.

The simplest generation system for tidal plants involves a dam, known as a barrage, across an inlet. Sluice gates on the barrage allow the tidal basin to fill on the incoming high tides and to empty through the turbine system on the outgoing tide, also known as the ebb tide. There are two-way systems that generate electricity on both the incoming and outgoing tides.

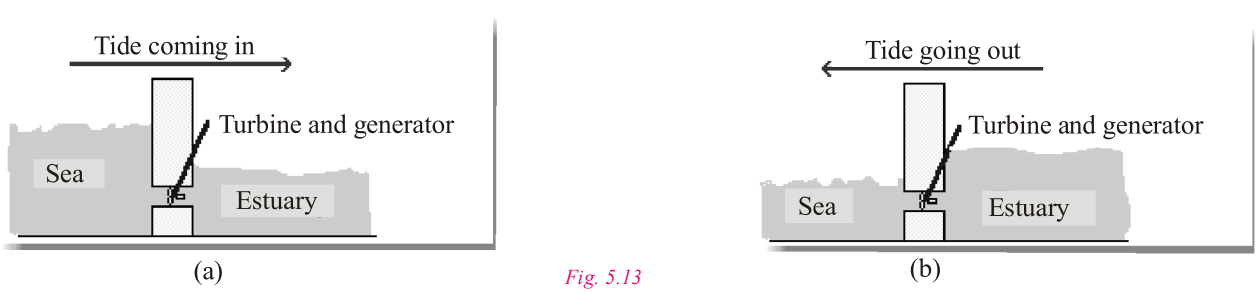


Fig. 5.13

Tidal energy is renewable. The tides will continue to ebb and flow, and the energy is there for the taking.

A major drawback of tidal power stations is that they can only generate when the tide is flowing in or out - in other words, only for 10 hours each day. However, tides are totally predictable, so we can plan to have other power stations generating at those times when the tidal station is out of action.

Tidal fences can also harness the energy of tides. A tidal fence has vertical axis turbines mounted in a fence. All the water that passes is forced through the turbines. They can be used in areas such as channels between two landmasses. Tidal fences have less impact on the environment than tidal barrages although they can disrupt the movement of large marine animals. They are cheaper to install than tidal barrages too.

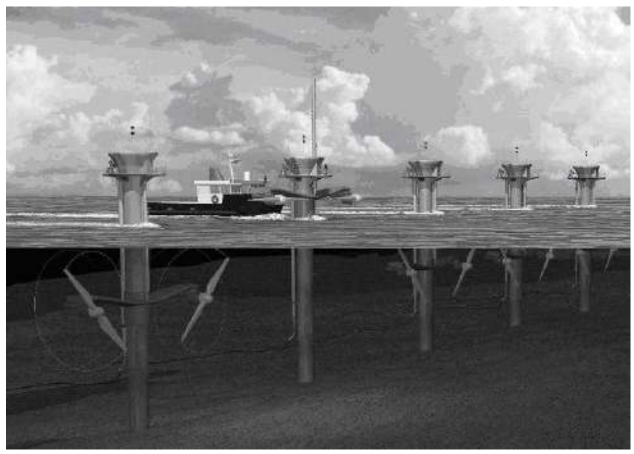


Fig : 5.14 Row of tidal current turbines

Advantages

- Tidal power is free.
- It needs no fuel.
- Not expensive to maintain.
- It produces no greenhouse gases or other waste.
- It produces electricity reliably.
- Tides are totally predictable.
- Offshore turbines and vertical-axis turbines are not ruinously expensive to build and do not have a large environmental impact.

Disadvantages

- A barrage across an estuary is very expensive to build, and affects a very wide area - the environment is changed for many miles upstream and downstream. Many birds rely on the tide uncovering the mud flats so that they can feed. There are few suitable sites for tidal barrages.
- Only provides power for around 10 hours each day, when the tide is actually moving in or out.

Why are there two high tides and two low tides per day?

Tides exist as the earth is affected by the non-uniform gravitational force from the moon. What is a non-uniform gravitational force? According to Newton's Law of universal gravitation, the gravitational force between two objects is inversely proportional to the square of the distance between them. That is, the shorter the distance, the greater the force, and the longer the distance, the weaker the force.

Please look at Figure. Point A experiences a greater lunar gravitational force than Point B (the earth's centre). Seawater is being attracted naturally towards the moon. A high tide is formed. Point C experiences a smaller lunar gravitational force than Point B, therefore the water level is higher here relative to Point B. Thus there are high tides at Point A and Point C, while the water levels at Point D and Point E are lower, that is, there are low tides.

During the rotation of the earth in one day, the location of the moon has no much change. Then a place on the earth will pass through two zones in which there are high tides. That is the reason why we see two high tides daily.

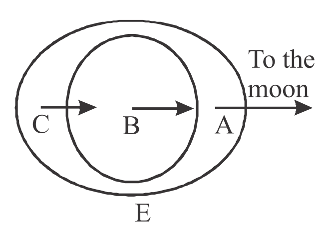


Fig : 5.15 The lunar gravitational force varies from place to place on the earth and this causes tides

Wave Energy

Kinetic energy (movement) exists in the moving waves of the ocean. Waves are a powerful source of energy. That energy can be used to power a turbine.

Fig : 5.16 (a)

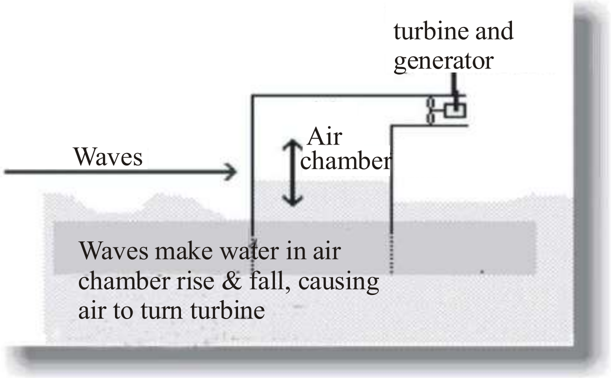


Fig. 5.16 (b)

There are several methods of getting energy from waves, but one of the most effective works like a swimming pool wave machine in reverse.

At a swimming pool, air is blown in and out of a chamber beside the pool, which makes the water outside bob up and down, causing waves.

At a wave power station, the waves arriving cause the water in the chamber to rise and fall, which means that air is forced in and out of the hole in the top of the chamber.

We place a turbine in this hole, which is turned by the air rushing in and out. The turbine turns a generator

Most wave-energy systems are very small. But, they can be used to power a warning buoy or a small light house.

Advantages

- The energy is free – no fuel needed, no waste produced.
- Not expensive to operate and maintain.
- Can produce a great deal of energy.

Disadvantages

- Depends on the waves – sometimes you'll get loads of energy, sometimes nothing.
- Needs a suitable site, where waves are consistently strong.
- Some designs are noisy.
- Must be able to withstand very rough weather.

Ocean Thermal Energy

The energy from the sun heats the surface water of the ocean. In tropical regions, the surface water can be 40º celsius or more degrees warmer than the deep water. This temperature difference can be used to produce electricity.

Ocean Thermal Energy Conversion (OTEC)

The idea is not new. Using the temperature of water to make energy actually dates back to 1881 when a French Engineer by the name of Jacques D'Arsonval first thought of OTEC. The final ocean energy idea uses temperature differences in the ocean. If you ever went swimming in the ocean and dove deep below the surface, you would have noticed that the water gets colder the deeper you go. It's warmer on the surface because sunlight warms the water. But below the surface, the ocean gets very cold. That's why scuba divers wear wet suits when they dive down deep. Their wet suits trapped their body heat to keep them warm.

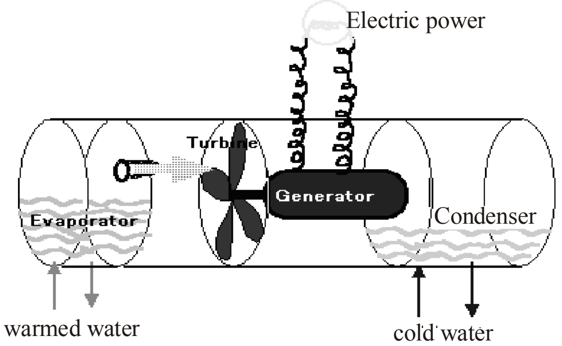


Fig : 5.17 OTEC system

OTEC generates electricity by using the temperature difference of 20°C (36°F) or more that exists between warm tropical waters at the sun-warmed surface, and colder waters drawn from depths of about 1000 m. To convert this thermal gradient into electrical energy, the warm water can be used to heat and vaporize a liquid (known as a working fluid). The working fluid develops pressure as it is caused to evaporate. This expanding vapor runs through a turbine generator and is then condensed back into a liquid by cold water brought up from depth, and the cycle is repeated.

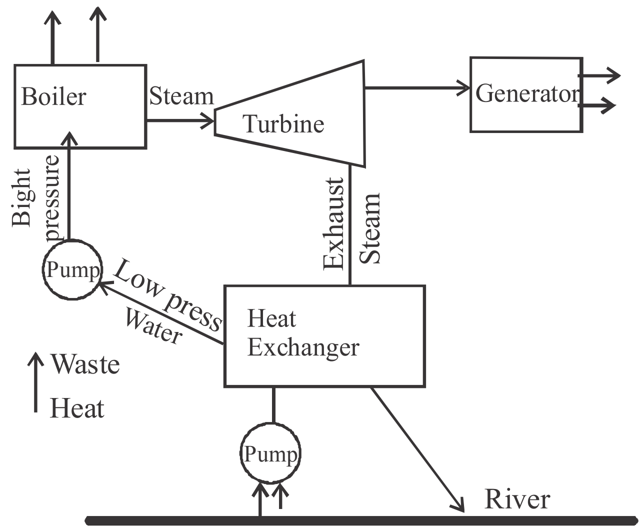


Fig : 5.18

There are potentially three basic types of OTEC power plants: closed-cycle, open-cycle, and various blendings of the two. All three types can be built on land, on offshore platforms fixed to the seafloor, on floating platforms anchored to the seafloor, or on ships that move from place to place

GEOTHERMAL ENERGY

Energy present in the depth of the earth is called geothermal energy. As we move inside the earth from the earth surface the temperature increases with increasing depth. Temperature in the earth at a distance of 10 kilometres is about 120°C and it increases to 300°C at the depth of 320 kilometres. It is evident that temperature increases with depth. Melted liquid, megma is present in the depth of earth. It is surrounded by various layers of soil, sand and water. Whenever there is some passage, it comes in contact with water present between these layers and converts this water into the steam of sufficient pressure. This vapour pressure can be used for production of energy.

There is a huge possibility of the use of this energy in India because here there are 340 hot geological sites. In Manikarn and Kalleshwar the possibilities of the use of geothermal energy are explored. One of the main characteristics of the geothermal energy is that, it is pollution free.

Due to geological changes, molten rocks formed in the deeper hot regions of earth's crust are pushed upward and trapped in certain regions called 'hot spots'. When underground water comes in contact with the hot spot, steam is generated. Sometimes hot water from that region finds outlets at the surface. Such outlets are known as hot springs.

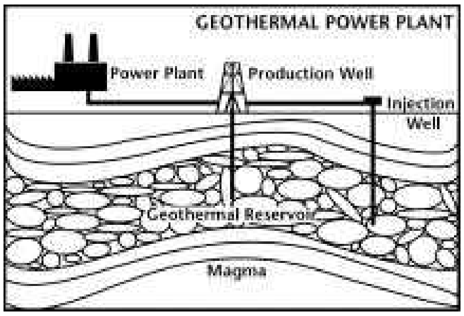


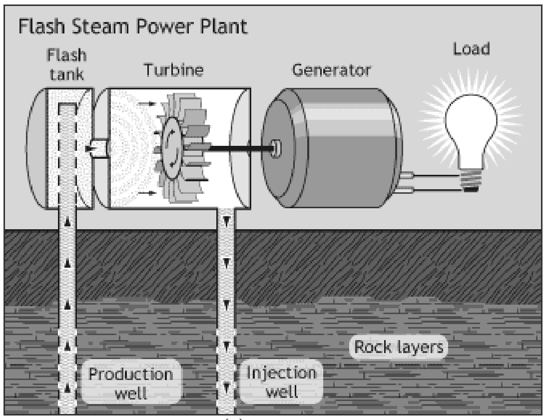
Fig : 5.19

Geothermal springs for power plants. The most common current way of capturing the energy from geothermal sources is to tap into naturally occurring "hydrothermal convection" systems where cooler water seeps into Earth's crust, is heated up, and then rises to the surface.

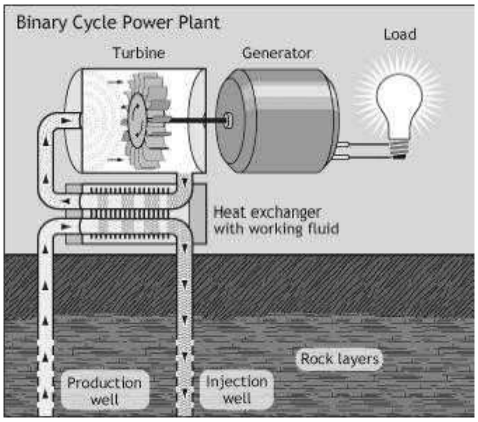
When heated water is forced to the surface, it is a relatively simple matter to capture that steam and use it to drive electric generators. Geothermal power plants drill their own holes into the rock to more effectively capture the steam.

There are three designs for geothermal power plants, all of which pull hot water and steam from the ground, use it, and then return it as warm water to prolong the life of the heat source. In the simplest design, the steam goes directly through the turbine, then into a condenser where the steam is condensed into water. In a second approach, very hot water is depressurized or "flashed" into steam which can then be used to drive the turbine.

In the third approach, called a binary system, the hot water is passed through a heat exchanger, where it heats a second liquid such as isobutane in a closed loop. The isobutane boils at a lower temperature than water, so it is more easily converted into steam to run the turbine. The systems are shown in the diagrams below.



(a)



(b)

Fig. 5.20

The choice of which design to use is determined by the resource. If the water comes out of the well as steam, it can be used directly, as in the first design. If it is hot water of a high enough temperature, a flash system can be used, otherwise it must go through a heat exchanger. Since there are more hot water resources than pure steam or high-temperature water sources, there is more growth potential in the heat exchanger design.

Direct use of geothermal heat. Geothermal springs can also be used directly for heating purposes. Hot spring water is used to heat greenhouses, to dry out fish and de-ice roads, for improving oil recovery, and to heat fish farms and spas.

Hot dry rock. Geothermal heat occurs everywhere under the surface of the earth, but the conditions that make water circulate to the surface are found only in less than 10 percent of Earth's land area. An approach to capturing the heat in dry areas is known as "hot dry rock." The rocks are first broken up by pumping high-pressure water through them. Water is then pumped from the surface down through the broken hot rocks. After the water heats up, it is brought back to the surface through a second well and used to drive turbines for electricity or to provide heat.

The main problem with geothermal, of course, is lack of easily accessible surface sites

Direct use and heating applications have almost no negative impact on the environment.

Geothermal power plants do not burn fuel to generate electricity, so their emission levels are very low. They release about 1 to 3 percent of the carbon dioxide emissions of a fossil fuel plant. Geothermal plants use scrubber systems to clean the air of hydrogen sulfide that is naturally found in the steam and hot water. Geothermal plants emit 97 per cent less acid rain - causing sulfur compounds than are emitted by fossil fuel plants. After the steam and water from a geothermal reservoir have been used, they are injected back into the earth.

In other places around the world, people used hot springs for rest and relaxation. The ancient Romans built elaborate buildings to enjoy hot baths, and the Japanese have enjoyed natural hot springs for centuries.

In Iceland, virtually every building in the country is heated with hot spring water. In fact, Iceland gets more than 50 per cent of its energy from geothermal sources. In Reykjavik, for example (population 115,000), hot water is piped in from 25 kilometers away, and residents use it for heating and for hot tap water.

NUCLEAR ENERGY

Nuclear power is an alternative energy source that can be obtained from either the splitting of the nuclei of atoms (nuclear fission) or the combining of the nuclei of atoms (nuclear fusion). In either of these two reactions, great amounts of energy are released. Nuclear power plants use a device called a nuclear reactor in which uranium or plutonium atoms are split in controlled fission reactions. The heat energy released is captured and used to generate electricity. Nuclear energy from Uranium is not renewable. Once we've dug up all the Earth's uranium and used it, there isn't any more.

Nuclear Fission

Nuclear fission was discovered by Otto Hahn and Strassman. *The process of splitting of a heavy nucleus into two lighter nuclei of comparable size and release of large energy is called nuclear fission*.

$_{92}U^{235} + {}_0n^1 \rightarrow {}_{92}U^{236} \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3_0n^1 + 200\text{Mev energy}$

U^{235} nucleus captures a thermal neutron. This forms a compound nucleus U^{236} in excited state.

The shape of nucleus is distorted and nucleus splits into two fragments emitting three neutrons..

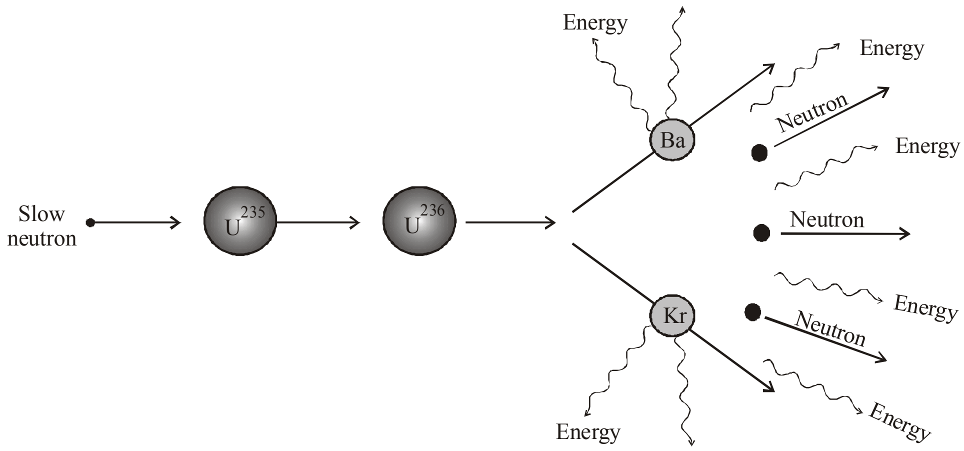


Fig. 5.21

The neutrons emitted in fission are fast neutrons. Their energy is about 2MeV. *On an average 2.5 neutrons are emitted per fission.* The binding energy per nucleon of products is greater than the reactants. The energy released in fission of Uranium is about 200 MeV. The fission energy released per nucleon is about 0.84 MeV. The fission of U^{235} may take place by different routes but amount of energy released per fission is nearly equal.

$_{92}U^{235} + {}_0n^1 \rightarrow {}_{92}U^{236} \rightarrow {}_{38}Sr^{95} + {}_{54}Xe^{139} + 2_0n^1$

$\rightarrow {}_{41}Nb^{99} + {}_{51}Sb^{133} + 4\ {}_0n^1 \rightarrow {}_{57}La^{148} + {}_{56}Br^{85} + 3\ {}_0n^1$ etc.

The fission fragments are highly radioactive. Nuclear fission can be explained on the basis of liquid drop model. The natural Uranium has following isotopes

$_{92}U^{234}(0.006\%)$; $_{92}U^{235}(0.72\%)$; $_{92}U^{238}(99.27\%)$

$_{92}U^{238}$ is not fissionable. This can be converted to plutonium which is fissionable by neutrons.

$_{92}U^{238} + {}_0n^1 \rightarrow {}_{93}Np^{239} + {}_{-1}e^0 + \overline{\nu}$

$_{93}Np^{239} \rightarrow {}_{94}Pu^{239} + {}_{-1}e^0 + \overline{\nu}$

The Uranium in which fraction of U^{235} is increased from 0.7% to 2.3% is called enriched Uranium.

Energy released per gram of Uranium :

Energy released per gm of Uranium

$$= \frac{\text{Avogadro number}}{\text{Mass number}} \times \text{Energy released per fission}$$

$$= \frac{6.023 \times 10^{23}}{235} \times 200 = 5.12 \times 10^{23}\,\text{MeV} = 5.12 \times 10^{23}\,\text{MeV}$$

$= 8.2 \times 10^{10}\,\text{J} = 2.28 \times 10^4\ \text{kWh} = 2 \times 10^{10}$ calorie

This energy is equivalent to : **(i)** Energy obtained by burning 2560 kg of coal

(ii) Energy obtained by burning 20 tonne of explosive TNT

The energy is released in the form of kinetic energy of fission fragments, γ–rays, heat, sound and light energy.

The fission process can take place at normal pressure and temperature.

Mass distribution in fission fragments

The mass distribution of fission fragments is highly asymmetric.

The curve shows two peaks at A = 95 and A = 139. These represent the most probable mass numbers obtained in fission fragments.

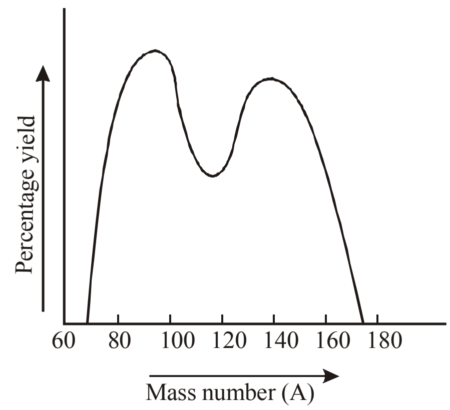


Fig. 5.22

The mass number of lighter fragment in nuclear fission is between 85 to 104.
The mass number of heavier fragment in nuclear fission is between 130 to 149.

Illustration : 5.1

The energy released per fission of Uranium is 200 MeV. Determine the number of fission per second required to generate 2MW power.

Sol. Energy obtained per fission

$= 200 \text{ MeV} = 200 \times 1.6 \times 10^{-13} \text{ J} = 3.2 \times 10^{-11} \text{ J}$

Number of fission per second required

$$= \frac{\text{Power}}{\text{Energy per fission}} = \frac{2\times10^{6}}{3.2\times10^{-11}} = 6.25\times10^{16}$$

CONNECTING TOPIC

CHAIN REACTION AND NUCLEAR REACTOR

Chain Reaction

In fission of Uranium atom 2.5 neutrons are produced on an average. In favourable conditions these may produce fission of other Uranium nuclei. At each stage number of neutrons available for fission gets multiplied which can cause further fission of Uranium nuclei. The process once started continues by itself till entire Uranium is consumed. This process is called nuclear chain reaction.

The neutrons produced in each fission may be lost due to following reasons:

(a) Leakage of neutrons from the system
(b) Absorption of neutrons by U^{238}
(c) Absorption of neutrons by impurities

Neutron multiplication factor

$$K = \frac{Rate\ of\ production\ of\ neutrons}{Rate\ of\ loss\ of\ neutrons}$$

(a) *If K = 1 the chain reaction is sustained.*

(i) This leads to a controlled chain reaction.

When only one of the neutron produced in each fission is able to produce fission then reaction is called **controlled chain reaction.**

(ii) The energy is produced at a uniform rate.
(iii) This forms working principle of nuclear reactor
(iv) The size of fissionable material is called critical size and its mass as critical mass.
(v) The minimum mass of Uranium for which chain reaction is possible is called critical mass. For U^{235} it is 10 kg.

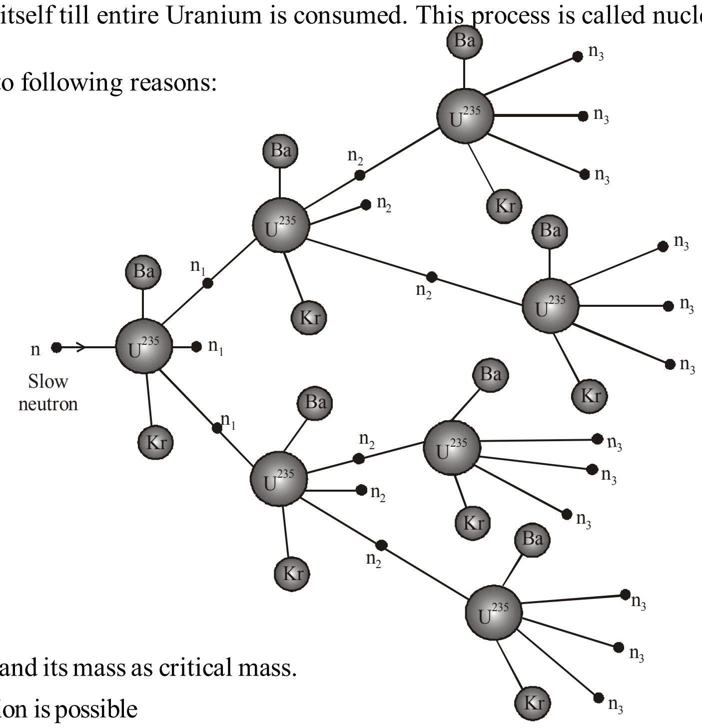


Fig. 5.23

(b) *If K > 1 the chain reaction is accelerated* because number of neutrons available for fission at each stage increases rapidly

(i) This leads to uncontrolled chain reaction

(ii) Energy is produced at rapidly increasing rate.

(iii) This is working principle of atom bomb.

(iv) The size of material is super critical.

(c) *If K < 1 the chain reaction stops* because number of neutrons available for fission decreases at each stage.

(i) The energy produced decreases

(ii) The size of material is sub critical

The rate of decay of neutrons is proportional to surface area of Uranium block. The rate of production of neutrons is proportional to number of nuclei present in Uranium block or volume of the block.

Controlled Chain Reaction in Nuclear Reactor

When only one of the neutron produced in each fission is able to produce fission then reaction proceeds slowly and is called controlled chain reaction.

Nuclear reactor is a device in which controlled nuclear chain reaction is initiated and maintained to produce energy.

Reactors are used :

(i) For power generation

(ii) To produce radioactive isotopes used in medicine, industry and agriculture

(iii) To produce Plutonium Pu^{239} used in making atom bomb

Thermal reactor:

A reactor in which energy is produced by fission of U^{235} by slow neutron is called thermal reactor.

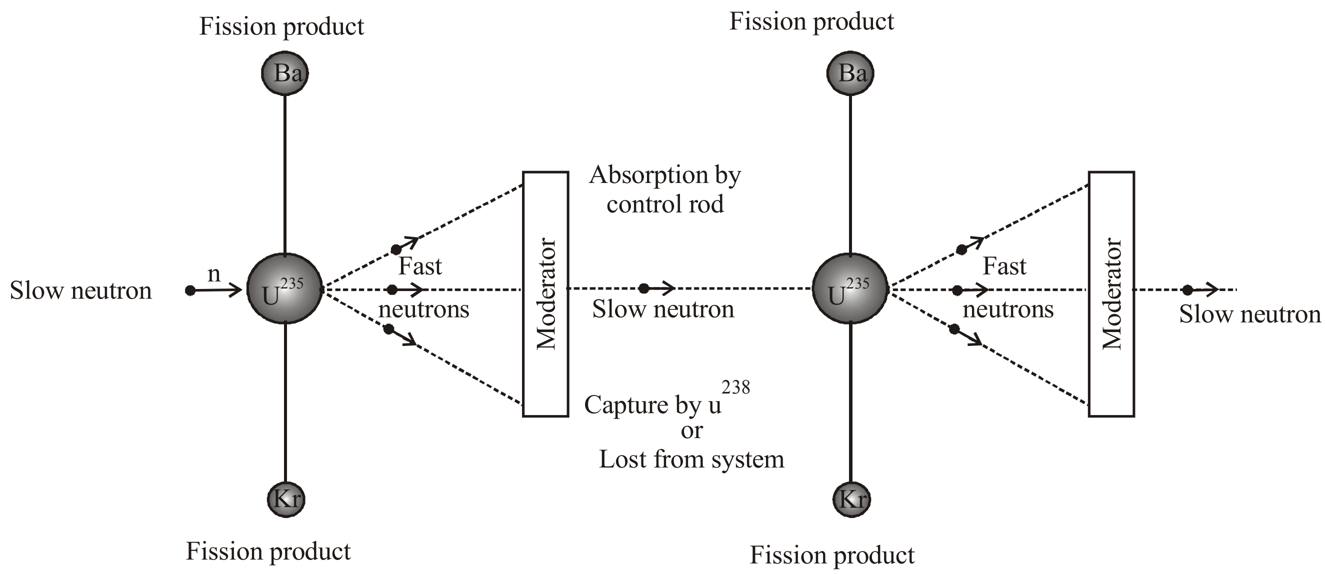


Fig. 5.24

Main Parts of Nuclear Reactor

(a) Fuel: It is fissionable material used for fission. The common fuels are U^{233}, U^{235}, Pu^{239} etc.

(b) Moderator : These are used to slow down the fast neutrons. e.g., Heavy water, graphite, beryllium oxide etc.

(c) Control rods : These help in controlling the rate of fission by absorbing the neutrons produced in fission. e.g. Cadmium rods.

(d) Coolant : A substance which is used to remove the heat produced and transfer it from core of nuclear reactor to the surrounding is called coolant. e.g. Air, water or carbondioxide.

(e) Shield: The whole reactor is protected with concrete walls 2 to 2.5 m thick so that radiations emitted during nuclear reactions do not produce harmful effects.

Breeder reactor : *A reactor which can produce more fissionable fuel than it consumes is called a breeder reactor.* No moderator is used in these reactors. Sodium is used as coolant. The mixture of natural Uranium and Plutonium works as fuel.

$${}_{92}U^{238} + {}_{0}n^{1} \longrightarrow {}_{92}U^{239} \longrightarrow {}_{92}U^{239} + \gamma$$

$$\downarrow$$

$$_{92}U^{239} \longrightarrow {}_{92}Np^{239} + _{-}\beta^{0} + \bar{\nu}$$

$$\downarrow$$

$$_{93}Np^{239} \longrightarrow {}_{92}Pu^{239} + _{-}\beta^{0} + \bar{\nu}$$

Using unfissonable $_{92}U^{238}$ we can produce fissionable $_{92}Pu^{239}$.

The chain reaction is maintained by fast neutrons. About 60 to 70% of natural Uranium is used in the process.

Nuclear Fusion

The process in which two or more lighter nuclei combine to form a heavy nucleus is known as nuclear fusion.

$$_{1}H^{2} + {}_{1}H^{2} \longrightarrow {}_{2}He^{4} + \text{Energy (24 MeV)}$$

The binding energy per nucleon of product is greater than the reactants. The energy released per nucleon is large $\simeq$ 6.75 MeV. Fusion is possible at high pressure ($\simeq 10^{6}$ atom) and high temperature ($\simeq 10^{8}$ ºC). The proton-proton cycle happens at lower temperature as compared to carbon-nitrogen cycle. Nuclear fusion is possible at a place which has reactants in large quantity. **Hydrogen bomb** works on the principle of nuclear fusion. The explosion of a hydrogen bomb needs an explosion of atom bomb to generate required temperature. No harmful radiations are produced in fusion.

ENVIRONMENTAL CONSEQUENCES

Exploiting any source of energy disturbs the environment in some way or the other. In any given situation, the source we would choose depends on factors such as the ease of extracting energy from that source, the economics of extracting energy from the source, the efficiency of the technology available and the environmental damage that will be caused by using that source. Research continues in these areas to produce longer lasting devices that will cause less damage throughout their life.

HOW LONG WILL AN ENERGY SOURCE LAST US ?

Renewable sources of energy are those which can be generated by us or which are constantly being generated by natural processes or whose supply is unlimited. Examples : The sun, wind, flowing water.

Non-renewable sources of energy are those which were produced in the past by natural processes, whose supply is limited and which we cannot generate again. Examples : Coal, petroleum, natural gas.

Renewable energy is available in our natural environment, in the form of some continuing or repetitive currents of energy, or is stored in such large underground reservoirs that the rate of depletion of the reservoir because of extraction of usable energy is practically negligible.

MISCELLANEOUS SOLVED EXAMPLES

1. **The efficiency of a kerosene stove is 40%. The heat produced on combustion of 1 gram of kerosene in the stove could raise the temperature of 100 gram of a liquid from 25°C to 25.3°C. If the specific heat capacity of the liquid be 0.6×10^3 kJ/kg °C. Calculate the calorific value of kerosene?**

Sol. Here, Mass of fuel consumed, m = 1 g

Mass of liquid, M = 100 g = 0.1 kg

Specific heat capacity of liquid, $C = 0.6 \times 10^3$ KJ/Kg °C

Rise of temperature of liquid, $\Delta T = (25.3 - 25.0) = 0.3°C$.

Efficiency of stove, $\eta = 40\% = 0.4$

Calorific value of kerosene, c = ? (to be calculated)

From relation of calorimetry heat gained by liquid, $Q = MC\ \Delta T$

Putting values, we get $Q = 0.1 \times 0.6 \times 10^3 \times 0.3 = 18$ kJ.

It is only 40% of the actual energy liberated by the kerosene

Actual heat liberated by the kerosene $= \dfrac{18 \times 100}{40} = 45$ kj

From relation, Q = mc

We have, $c = \dfrac{Q}{m}$; Putting values, we get $c = \dfrac{45}{1} = 45$.

Calorific value = 45 KJ/g

2. **The heat produced by burning of a cow dung cake of mass 210 g raises the temperature of 50 g of water by 2°C. Assuming that all the heat was utilized for heating water whose specific heat capacity is 4.2 J/g°C, Calculate the calorific value of the dung cake?**

Sol. Here, Mass of fuel burnt, m = 210 g

Mass of water heated, M = 50 g

Rise of temperature of water, $\Delta T = 2°C$

Specific heat capacity of water, C = 4.2 J/g°C

Calorific value of fuel, c = ? (to be calculated)

From relation, of calorimetry, $Q = 50 \times 4.2 \times 2 = 420$ J

From relation, Q = mc

We have, $c = \dfrac{Q}{m}$; Putting value, we get, $c = \dfrac{420}{210} = 2$

i.e., Calorific value of cow dung cake, c = 2 J/g.

3. **Heat produced on burning 5.0 g of a fuel raises the temperature of 1.0 kg water from 20°C to 60°C. If the specific heat of water be 4.2 J/g°C, calculate the calorific value of the fuel?**

Sol. Here, mass of the fuel burnt, m = 5 g

Mass of water heated, M = 1.0 kg = 1000 g

Rise of temperature of water, $\Delta T = (60 - 20) = 40°C$

Specific heat capacity of water, C = 4.2 J/g °C

Calorific value of fuel, c = ? (to be calculated)

From relation of calorimetry, Heat gained by water, $Q = MC\ \Delta T$

Putting values, we get $Q = 1000 \times 4.2 \times 40 = 168000$ J

From relation, Q = mc;

We have, $c = \dfrac{Q}{m}$; Putting values, we get $c = \dfrac{168000}{5} = 33600$ J/g

Calorific value of fuel, c = 33.6 kJ/g.

SOLVED EXAMPLES BASED ON CONNECTING TOPICS

4. Find the disintegration energy Q for the fission event represented by equation

$$_{92}U^{235} + {}_0n^1 \longrightarrow {}_{92}U^{236} \longrightarrow {}^{140}_{58}Ce + {}^{94}_{40}Zr + {}_0n^1$$

Some required data are :

Mass of $_{92}U^{235}$ = 235.0439 u

$_0n^1$ = 1.00867 u

$^{140}_{58}Ce$ = 139.9054 u

$^{94}_{40}Zr$ = 93.9063 u

Find energy released in the process.

Sol. The mass lost in the process

$\Delta m = 235.0439 - (139.9054 + 93.9063 + 1.00867)$

$= 0.22353$ u

The corresponding energy released

$= \Delta mc^2$

$= (0.22353)(3 \times 10^8)^2$ J

$= 208$ MeV

5. What is the power output of a $_{92}U^{235}$ reactor if it takes 30 days to use up 2 kg of fuel, and if each fission gives 185 MeV of usable energy?

Sol. The number of $_{92}U^{235}$ in 2 kg,

$$N = \frac{(2 \times 1000)}{235} \times 6.02 \times 10^{23}$$

$$= 5.12 \times 10^{24}$$

The fission of each $_{92}U^{235}$ produces energy

$= 185$ MeV

$\therefore$ Total energy produces,

$$E = (5.12 \times 10)^{24} \times (185 \times 1.6 \times 10^{-13}) J$$

$$= 1572.3 \times 10^{11} \text{ J}$$

The power output $P = \frac{E}{t} = \frac{1572.3 \times 10^{11}}{30 \times 24 \times 3600}$

1 EXERCISE

Fill in the Blanks :

DIRECTIONS : *Complete the following statements with an appropriate word / term to be filled in the blank space(s).*

1. Many of the sources ultimately derive their energy from the............
2. A device that utilises solar energy for cooking purposes is called a ....
3. A solar cell is a device which converts solar energy directly into ....
4. The energy possesses by wind is called ....
5. The flowing water possesses .... energy
6. Electricity generated from sea waves is ....
7. The internal heat of an earth is known as .... energy.
8. Bio-gas is a mixture of ...., carbon dioxide, ... and ....
9. When a complex material is heated strongly in the absence of air, then it decomposes to the simplest substance. This process is called ....
10. The material obtained from the bodies of plants and animals is called ....
11. Coal gas is mixture of ...., ... and ....
12. Coal, petroleum and .... are the three important source of modern fuels.

True / False :

DIRECTIONS : *Read the following statements and write your answer as true or false.*

1. Our energy requirements increase with our standard of living.
2. In order to fulfil our energy requirements, we try to improve the efficiency of energy usage and also try and exploit new sources of energy.
3. The main constituent of biogas is not methane.
4. Black colour is a very good absorber of heat and good reflector.
5. The use of geothermal energy cause pollution.
6. Deep drilling in the earth to obtain geothermal energy is very difficult.
7. Charcoal is a better fuel than wood and coal.
8. Biogas is a better fuel than animal dung-cakes.
9. The calorific value of methane is less than that of butane.
10. Producer gas is obtained as one of the products of dry distillation of coal.
11. The sun is an ultimate source of fossil fuel.
12. Coal gas is an example of primary fuel.
13. Natural gas is renewable source of energy.
14. Gobar gas is a non-renewable source of energy.
15. Solar cookers make use of solar energy.
16. The sun is the ultimate source of energy.

Match the Following :

DIRECTIONS : *Each question contains statements given in two columns which have to be matched. Statements in column I have to be matched with statements in column II.*

1.

Column I	Column II
A. Peat	p. liquid fuel
B. Alcohol	q. 27% of carbon
C. Decay of biomass	r. Difference in temperature between warm surface waters and colder waters.
D. Rise and fall of water levels in oceans	s. biogas
E. OTEC	
F. Ultimate source of energy	t. tidal energy
	u. sun
G. Stored in food grains	v. wind
H. Moving air	w. bioenergy

Very Short Answer Questions:

DIRECTIONS : *Give answer in one word or one sentence.*

1. Why CNG considered as environmental friendly fuel ?
2. Name two main combustible components of biogas.
3. Name the major constituent of natural gas.
4. State the energy transformation taking place when a boy is ridding a bicycle.
5. Name the main constituents of bio-gas.
6. In what respect fuel oil is better than coal ?
7. How has the traditional use of wind and water energy been modified for our convenience?
8. What is geothermal energy?
9. Name two energy sources that you would consider to be renewable. Give reasons for your choices.
10. Give the names of two energy sources that you would consider to be exhaustible. Give reasons for your choices.
11. On what basis would you classify energy sources as (a) renewable and non-renewable? (b) exhaustible and inexhaustible?
    Are the options given in (a) and (b) the same?
12. What is a turbine?
13. What do you mean by hydro energy?
14. What do you mean by tidal energy?
15. Why it is not possible to use the energy which is consumed?
16. What energy transformation takes place when we light a

candle and drop a metal plate from a certain height?
17. What are fossil fuels?
18. What was the most common source of heat energy in ancient times?
19. Which fuel meets the growing demand of energy nowadays and the past?
20. Why most of the thermal power plants are set near coal or oil mines?
21. Why hydro power plants are associated with dams?
22. What energy transformation takes place in the solar cooker?
23. What is a solar cooker?
24. Which part of sunlight is used in heating a solar cooker?
25. What is a solar geyser?

Short Answer Questions :

DIRECTIONS : *Give answer in 2-3 sentences.*

1. List out the different power plants from which we get electrical energy?
2. What are the advantages and disadvantages of using energy from water?
3. What is biomass and write few examples of biomass?
4. How is charcoal formed and what are the advantages of using charcoal as a source of energy?
5. What is the major disadvantage of biomass and how can it be overcome ?
6. Write the different parts of a box type solar cooker.
7. Explain the working of a solar cooker.
8. Which type of solar spectrum is trapped in the solar cooker?
9. What is the cause for the tides on the ocean? (or) how are tides formed?
10. How wave energy is an indirect form of solar energy?
11. What are the limitations of harnessing wave energy?
12. What is OTEC?
13. What is the minimum requirement to operate the OTEC system?
14. List out the energies that are dependent and non-dependent of solar energy?
15. What are hot spots?
16. Why hot spots are important in harnessing Geothermal energy?
17. Name a few cites where geothermal energy is harnessed?
18. What are the limitations of harnessing Geothermal energy?
19. What are the advantages and disadvantages of Geothermal energy?
20. Write four functions performed by the sun's energy.

Long Answer Questions :

DIRECTIONS : *Give answer in 4 to5 sentences.*

1. Write the working of a hydro power plant with a neat diagram?
2. Draw the schematic picture a solar cooker?
3. Electricity generated at hydroelectric power stations is considered to be another form of solar energy. Explain.
4. (a) Describe the steps involved in obtaining biogas and explain what is meant by anaerobic decomposition.
   (b) Which isotope of uranium can undergo fission readily?
5. Hydroenergy is an indirect source of solar energy. Justify this statement.
6. Explain what causes the wind to blow in equatorial regions. What is wind energy?
7. What is biogas? How can biogas be obtained? Why is the use of biogas obtained from cow dung advised in preference to burning of cow dung cakes?
8. Name three forms in which energy from ocean is made available for use. What are OTEC power plants ? How do they operate ?
9. Describe the construction of solar cooker. How does it cause rise in temperature to cook food?
10. (i) Distinguish between renewable and non-renewable sources of energy giving one example of each.
    (ii) Why is the use of wood as a fuel not advised although forests can be replenished?

2 EXERCISE

Text-Book Questions :

1. What is a good source of energy ?
2. What is a good fuel ?
3. If you could use any source of energy for heating your food, which one would you use and why?
4. What are the disadvantages of fossil fuels ?
5. Why are we looking at alternate sources of energy?
6. How has the traditional use of wind & water energy been modified for our convenience ?
7. What kind of mirror-concave, convex or plane- would be best suited for use in a solar cooker? Why?
8. What are the limitations of the energy that can be obtained from the oceans?
9. What is geothermal energy ?
10. What are the advantages of nuclear energy?
11. Can any source of energy be pollution-free? Why or why not?
12. Hydrogen has been used as a rocket fuel. Would you consider it a cleaner fuel than CNG ?Why or why not?
13. Name two energy sources that you would consider to be renewable. Give reasons for your choices.
14. Give the names of two energy sources that you would consider to be exhaustible. Give reasons for your choices.

Text-Book Exercises :

1. A solar water heater cannot be used to get hot water on
   (a) a sunny day. (b) a cloudy day.
   (c) a hot day. (d) a windy day.
2. Which of the following is not an example of a biomass energy source?
   (a) Wood (b) Gobar-gas
   (c) Nuclear energy (d) Coal
3. Most of the sources of energy we use represent stored solar energy. Which of the following is not ultimately derived from the Sun's energy?
   (a) Geothermal energy (b) Wind energy
   (c) Nuclear energy (d) Biomass.
4. Compare and contrast fossil fuels and the Sun as direct sources of energy.
5. Compare and contrast biomass and hydro electricity as sources of energy.
6. What are the limitations of extracting energy from –
   (a) the wind? (b) waves? (c) tides?
7. On what basis would you classify energy sources as
   (a) renewable and non-renewable?
   (b) exhaustible and inexhaustible?
   Are the options given in (a) and (b) the same?
8. What are the qualities of an ideal source of energy?
9. What are the advantages and disadvantages of using a solar cooker? Are there places where solar cookers would have limited utility?
10. What are the environmental consequences of the increasing demand for energy?
    What steps would you suggest to reduce energy consumption?

Exemplar Questions :

1. What are the environmental consequences of using fossil fuels? Suggest the steps to minimise the pollution caused by various sources of energy including non-conventional sources of energy.
2. Why there a need to harness non-conventional source of energy? Give two main reasons.
3. What is the role of a plane mirror and a glass sheet in a solar cooker?
4. Mention three advantages of a solar cell?
5. What are the limitations in obtaining energy from wind?
6. Why is there a need for harnessing non-conventional sources of energy? How can energy be harnessed from the sea in different ways?

Hots Questions :

1. "A burning match stick can ignite a piece of paper or an incense stick but cannot burn a wooden block". Given reasons.
2. Suppose a green tree absorbs, on an average, 10^8J of solar energy per day, incident on it and the tree could convert 1% of the solar energy incident on it to produce wood, how many days would it take to produce 50 kg of wood? (The calorific value of wood is 15 kJ g^{-1}).
3. Water that falls from a waterfall is used to generate electricity. If the height of water fall is 100 m and $10^2 m^3$ of water falls every minute, then find the hydel energy in MW h generated in one day. Assume that 60% of the energy of the flowing water is converted into electricity. (Take density of water as 1000 kg m^{-3}).
4. Among methane (CH_4) and methyl alcohol (CH_3OH) which is a better fuel and why?
5. 10 kg of water at 30ºC is heated to its boiling point on a stove that uses LPG as fuel. If the efficiency of the stove is 70%, then find the mass of the fuel that is consumed. Take the calorific value of LPG (Butane) as 55,000 kJ kg^{-1}.
6. Find the electrical power generated in 1s by a wind mill that is erected in a location when air flows with an average speed of 54 km h^{-1}. Assume that the moving air is completely stopped by the blades of the wind turbine of area 10 m^2, over which air flows normally and the energy conversion from wind energy to electrical energy is only 50%. (Take density of air = 0.3 kg m^{-3})
7. Why is geothermal energy better than wind energy for power generation?
8. The sun is the ultimate source of energy on earth. Is the given statement true with respect to fossil fuels?

9. Explain why :
(i) It is difficult to burn a piece of wood fresh from a tree.
(ii) Pouring dry sand over the fire extinguishes it.
(iii) It is difficult to use hydrogen as a source of energy.
(iv) Charcoal is considered a better fuel than wood.
10. Name the major fuel component of biogas. What are its other combustible components ? What is the use for the residual slurry and why ?
11. What is the main basic cause for wind to blow ? Name a part of India where wind energy is commercially harnessed. Compare wind power and power of water flow in respect of generating mechanical and electrical energies. What is the hindrance in developing them ?

3 EXERCISE

Single Option Correct :

DIRECTIONS: *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. Which of the following is a non-renewable source of energy?
(a) Wood (b) Sun
(c) Fossil fuels (d) Wind
2. Acid rain happens because
(a) sun leads to heating of upper layer of atmosphere
(b) burning of fossil fuels release oxides of carbon, nitrogen and sulphur in the atmosphere
(c) electrical charges are produced due to friction amongest clouds
(d) earth atmosphere contains acids
3. In a hydro power plant
(a) Potential energy possessed by stored water is converted into electricity
(b) Kinetic energy possessed by stored water is converted into potential energy
(c) Electricity is extracted from water
(d) Water is converted into steam to produce electricity
4. Which is the ultimate source of energy?
(a) Water (b) Sun
(c) Uranium (d) Fossil fuels
5. Ocean thermal energy is due to
(a) energy strored by waves in the ocean
(b) temperature difference at different levels in the ocean
(c) pressure difference at different levels in the ocean
(d) tides arising out in the ocean
6. Which part of the solar cooker is responsible for green house effect?
(a) Coating with black colour inside the box
(b) Mirror
(c) Glass sheet
(d) Outer cover of the solar cooker
7. The main constituent of biogas is
(a) methane (b) carbon dioxide
(c) hydrogen (d) hydrogen sulphide
8. The power generated in a windmill
(a) is more in rainy season since damp air would mean more air mass hitting the blades
(b) depends on the height of the tower
(c) depends on wind velocity
(d) can be increased by planting tall trees close to the tower
9. Choose the correct statement
(a) Sun can be taken as an inexhaustible source of energy
(b) There is infinite storage of fossil fuel inside the earth
(c) Hydro and wind energy plants are non polluting sources of energy
(d) Waste from a nuclear power plant can be easily disposed off
10. Choose the incorrect statement regarding wind power
(a) its temperature increases
(b) larger amount of potential energy is converted into kinetic energy
(c) the electricity content of water increases with height
(d) more water molecules dissociate into ions
11. Choose the incorrect statement regarding wind power
(a) It is expected to harness wind power to minimum in open space
(b) The potential energy content of wind blowing at high altitudes is the source of wind power
(c) Wind hitting at the blades of a windmill causes them to rotate The rotation thus achieved can be utilised further
(d) One possible method of utilising the energy of rotational motion of the blades of a windmill is to run the turbine of an electric generator
12. Most of the energy we use originally came from
(a) the sun (b) the air
(c) the soil (d) the oceans
13. Electrical energy can be produced from
(a) mechanical energy (b) chemical energy
(c) radiant energy (d) All of the above

14. Coal, petroleum, natural gas, and propane are fossil fuels. They are called fossil fuels because:
(a) they are burned to release energy and they cause air pollution
(b) they were formed from the buried remains of plants and tiny animals that lived hundred of millions of years ago
(c) they are nonrenewable and will run out
(d) they are mixed with fossils to provide energy
15. Gasoline is produced by refining which fossil fuel?
(a) natural gas (b) coal
(c) petroleum (d) propane
16. Propane is used instead of natural gas on many farms and in rural areas. Why is propane often used instead of natural gas?
(a) it's safer (b) it's portable
(c) it's cleaner (d) it's cheaper
17. What sector of the Indian economy consumes most of the nation's petroleum?
(a) residential (b) commercial
(c) industrial (d) transportation
18. Natural gas is transported mainly by
(a) pipelines (b) trucks
(c) barges (d) all three equally
19. Global warming focuses on an increase in the level of which gas in the atmosphere?
(a) ozone (b) sulfur dioxide
(c) carbon dioxide (d) nitrous oxide
20. Solar, biomass, geothermal, wind, and hydropower energy are all renewable sources of energy. They are called renewable because they
(a) are clean and free to use
(b) can be converted directly into heat and electricity
(c) can be replenished by nature in a short period of time
(d) do not produce air pollution
21. Today, which renewable energy source provides the India with the most energy?
(a) wind (b) solar
(c) geothermal (d) hydropower
22. How much of the energy in burning coal reaches the consumer as electricity
(a) 1/3 (one-third) (b) 1/2 (one-half)
(c) 3/4 (three-quarters) (d) 9/10 (nine-tenths)
23. Which form of energy is contained in wind energy
(a) Kinetic energy (b) Potential energy
(c) Electric energy (d) Thermal energy
24. In biogas, which gas is present in maximum amount
(a) Carbon dioxide (b) Methane
(c) Hydrogen (d) Oxygen
25. Which one of the following is not a source of non-convential energy
(a) Coal (b) Solar energy
(c) Wind energy (d) Biogas
26. White energy is freely available in ample amount of
(a) Sunlight (b) Water gas
(c) Hydrogen (d) Wind energy
27. Gobar gas is
(a) foul smelling gas
(b) sweet smelling gas
(c) having high caloric value
(d) useless
28. Biogas is produced from biomatter by
(a) anaerobic fermentation
(b) distructing distillation
(c) fractional distillation
(d) mixing petrol in biomatter
29. L.P.G. is mostly liquified
(a) hydrogen (b) oxygen
(c) butane (d) methane
30. A solar water heater cannot be used to get hot water on
(a) a sunny day (b) a cloudy day
(c) a hot day (d) a windy day
31. Which of the following is not an example of a biomass energy source
(a) wood (b) gobargas
(c) nuclear energy (d) coal
32. Most of the sources of energy we use represent stored solar energy. Which of the following is not ultimately derived from the Sun's energy?
(a) geothermal energy (b) wind energy
(c) nuclear energy (d) bio-mass.
33. An example of secondary fuel is
(a) coal (b) water gas
(c) natural gas (d) petroleum
34. Which of the following is an example of fossil fuel
(a) coal gas (b) coke
(c) natural gas (d) producer gas
35. Most of the fuels are
(a) carbon compounds with sulphur
(b) nitrogen compounds with carbon
(c) carbon compounds with hydrogen
(d) none of these
36. Producer gas is a mixture of
(a) carbon monoxide and nitrogen gas
(b) carbon monoxide and hydrogen gas
(c) carbon monoxide and water vapour
(d) carbon monoxide and nitrous oxide
37. The fractional distillation of coal tar yields
(a) carbon disulphide (b) carbon tetrachloride
(c) kerosene oil (d) benzene
38. Which of the following is not used as a rocket fuel?
(a) synthetic rubber (b) liquid hydrogen
(c) paraffin (d) liquid nitrogen
39. The fraction of the sun's energy received on earth is about
(a) 12% (b) 26%
(c) 38% (d) 47%
40. Which of the following source of energy is different from others?
(a) coal (b) lignite
(c) petroleum (d) plants
41. Which of the following source of energy is different from others
(a) bitumen (b) anthracite
(c) coke (d) gobar gas
42. Choose the only renewable source of energy
(a) coal (b) uranium
(c) natural gas (d) geothermal power

43. Which of the following is a false statement?
(a) To overcome the energy crisis the use of solar cooker must be increased.
(b) To overcome the energy crisis more amount of non-renewable sources of energy must be used.
(c) The re-usage of waste material as a source of energy can be done to overcome the energy crisis.
(d) To overcome the energy crisis water has to be saved.

44. The main constituent of LPG is butane. Then
(A) butane can be liquefied easily under high pressure.
(B) butane is liquefied by chemically reacting with ethane and propane.
(a) Only A is true
(b) Only B is true
(c) Both A and B are true
(d) Both A and B are false

45. Which element contained in a fuel contributes to its high calorific value?
(a) Carbon (b) Hydrogen
(c) Oxygen (d) Nitrogen

46. Combustion, the process of burning a fuel, is
(A) an oxidation and an exothermic reaction.
(B) a reduction and an endothermic reaction.
(a) Only A is true
(b) Only B is true
(c) Both A and B are true
(d) Both A and B are false

47. .... is used as a fuel in spaceships.
(a) Hydrogen (b) Alcohol
(c) Petrol (d) Diesel

48. In solar water heater, a copper pipe with its outer surface painted in black is fixed in the form of a coil in box.
(a) The only purpose of bending copper pipe is to increase the capacity of water storage.
(b) Bending copper pipe as a coil helps to increase the surface area for heating.
(c) Both (1) and (2) are true
(d) Both (1) and (2) are false

49. In the extraction of some metals from their ores, coke can be used as a /an
(a) oxidizing agent (b) reducing agent
(c) catalyst (d) flux

50. Find the false statement from the following statements given below:
(a) Geothermal power plants cannot operate round the clock.
(b) The initial cost in setting up this plant will be high.
(c) This type of source is free and renewable.
(d) Operating cost involved in a geothermal plant is less.

51. Is used to produce energy in OTEC.
(a) Tidal energy
(b) Temperature difference between the different layers of water in ocean
(c) Ocean waves
(d) None of the above

52. The curde oil extracted from the earth is separated into its constituents by a process called
(a) disintegration distillation
(b) compound idstillation
(c) destructive distillation
(d) fractional distillation

53. Among the following the sources of energy for which source sun is not a chief source of energy is
(a) Hydroelectric power plant
(b) Ocean thermal energy conversion (OTEC)
(c) Tidal energy
(d) Biomass

54. A good fuel should
(a) be safe to store and transport
(b) be able to provide desired quantity of energy at a steady rate over a long period of time
(c) have low content of non-combustibles and no combustion products that are poisonous or environmental pollutants
(d) All the above

More than One Option Correct :

DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

1. Which of the following are true statements?
(a) To overcome the energy crisis the use of solar cooker must be increased.
(b) To overcome the energy crisis more amount of non-renewable sources of energy must be used.
(c) The re-usage of waste material as a source of energy can be done to overcome the energy crisis.
(d) To overcome the energy crisis water has to be saved.

2. Which of the following are renewable sources of energy?
(a) Wood (b) Sun
(c) Fossil fuels (d) Wind

3. Ocean thermal energy is not due to
(a) energy strored by waves in the ocean
(b) temperature difference at different levels in the ocean
(c) pressure difference at different levels in the ocean
(d) tides arising out in the ocean

4. Choose the incorrect statements
(a) Sun can be taken as an inexhaustible source of energy
(b) There is infinite storage of fossil fuel inside the earth
(c) Hydro and wind energy plants are non polluting sources of energy
(d) Waste from a nuclear power plant can be easily disposed off

5. Choose the correct statements regarding wind power
(a) It is expected to harness wind power to minimum in open space
(b) The potential energy content of wind blowing at high altitudes is the source of wind power
(c) Wind hitting at the blades of a windmill causes them to rottate The rotation thus achieved can be utilised further
(d) One possible method of utilising the energy of rotational motion of the blades of a windmill is to run the turbine of an electric generator

6. Choose the correct statements?
   (a) We are encouraged to plant more trees so as to ensure clean environment and also provide bio-mass fuel
   (b) Gobar-gas is produced when crops, vegetable wastes, etc., decompose in the absence of oxygen
   (c) The main ingredient of bio-gas is ethane and it gives a lot of smoke and also produces a lot of residual ash
   (d) Bio-mass is a renewable source of energy

Assertion & Reason :

DIRECTIONS : *Each of these questions contains an Assertion followed by reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.
(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.
(c) If **Assertion** is **correct** but **Reason** is **incorrect**.
(d) If **Assertion** is **incorrect** but **Reason** is **correct**.

1. **Assertion :** Nuclear forces are independent of charges.
   Reason : Nuclear force is not a central force.
2. **Assertion :** U^{235} nucleus, by absorbing a slow neutron undergoes nuclear fission with the evolution of a significant quantity of heat
   Reason : During nuclear fission a part of the original mass of U^{235} is lost and gets converted into heat.
3. **Assertion :** In street light circuits, photo-cells are used to switch on and off the lights automatically at dusk and dawn.
   Reason : A photocell can convert a change in intensity of illumination into a change in photocurrent that can be used to control lighting system.

Multiple Matching Questions :

DIRECTIONS : *Following question has four statements (A, B, C and D) given in Column I and 4 statements (p, q, r and s) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

1.

Column A	Column B
(A) Ramagundam thermal plant is in	(p) Andhra Pradesh
(B) Raichur thermal plant is in	(q) Karnataka
(C) Korba thermal plant is in	(r) Madhya Pradesh
(D) Farraka thermal plant is in	(s) West Bengal

	A	B	C	D
(a)	r	s	p	q
(b)	p	r	s	q
(c)	q	p	r	s
(d)	p	q	r	s

Integer/ Numeric Questions :

DIRECTIONS : *Following are integer based/Numeric based questions. Each question, when worked out will result in one integer or numeric value.*

1. How much energy will 1 kg mass of wood yield on complete combustion, if its calorific value were 15 kJ/g?
2. Suppose the average solar energy incident on the green leaves (canopy) of a tree were 10^8 J per day. The calorific value of the wood obtained from this tree is 15 kJ/g. If the tree could convert 1% of the incident solar energy as wood, how many days will it take to produce 10 kg of wood?
3. 0.06 kg of kerosene oil is used to heat 500 gms of water so that its temperature rises from 20°C to 70°C. Find CV of kerosene oil (S = 4.2 J/g/°C)?
4. The heat produced on complete combustion of 10 gm of fuel raises the temperature of 2 kg of water from 20°C to 70°C. Find the CV of the fuel if C = 4.2 J/kg/°C?
5. A family consumes 14 kg of LPG in 30 days. If Calorific value of LPG is 50 KJ/gm, find average energy consumption per day?
6. A family consumes 10 kg of kerosene oil in 30 days. Find average energy consumption for a day if CV of kerosene oil is 45 kJ/gm?
7. Find the CV of methane according to the following reaction :-
   $$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O + 805\,\text{kJ}$$
8. CV of a fuel is 50 kJ/gm. How many grams of this fuel will be required to raise the temperature of 2 kg of water by 40°C (S = 4,200 J/kg/°C)?
9. If mass equivalent to one mass of proton is completely converted into energy then determine the energy produced?
10. The energy released per fission of uranium is 200 MeV. Determine the number of fission per second required to generate 2MW power.
11. Determine the energy released in the process ${}_1H^2 + {}_1H^2 \longrightarrow {}_2He^4 + Q$
    Given M $({}_1H^2) = 2.01471$ amu M $({}_2He^4) = 4.00388$ amu
12. A neutron is absorbed by a ${}_3Li^6$ nucleus with subsequent emission of an alpha-particle. The corresponding nuclear reaction is
    $${}_3Li^6 + {}_0n^1 \rightarrow {}_2He^4 + {}_1H^3$$
    Calculate the energy release in this reaction.
    Given
    $$m\left({}_3Li^6\right) = 6.015126 \text{ amu}$$
    $$m\left({}_2He^4\right) = 4.0026044 \text{ amu}$$
    $$m\left({}_0n^1\right) = 1.0086654 \text{ amu}$$
    $$m\left({}_1H^3\right) = 3.016049 \text{ amu}$$

4 ADVANCED EXERCISE
BASED ON CONNECTING TOPICS

DIRECTIONS (Qs. 1-9) : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. The control rod in a nuclear reactor is made of
(a) Uranium (b) Cadmium
(c) Graphite (d) Plutonium

2. The process by which a heavy nucleus splits into light nuclei is known as
(a) Fission (b) α – decay
(c) Fusion (d) Chain reaction

3. The explosion of the atomic bomb takes place due to
(a) Nuclear fission (b) Nuclear fusion
(c) Scattering (d) Thermionic emission

4. In nuclear reaction ${}_2He^4 + {}_zX^A \to {}_{z+2}Y^{A+3} + A$, A denotes
(a) Electron (b) Positron
(c) Proton (d) neutron

5. Which of the following is the fusion reaction
(a) ${}_1H^2 + {}_1H^2 \to {}_2He^4$
(b) ${}_0n^1 + {}_7N^{14} \to {}_6C^{14} + {}_1H^1$
(c) ${}_0n^1 + {}_{92}U^{238} \to {}_{93}Np^{239} + \beta^{-1} + \gamma$
(d) ${}_1H^3 \to {}_2He^3 + \beta^{-1} + \gamma$

6. What is used as a moderator in a nuclear reactor?
(a) Water (b) Graphite
(c) Cadmium (d) Steel

7. The functions of moderators in nuclear reactor is to
(a) Decrease the speed of neutrons
(b) Increase the speed of neutrons
(c) Decrease the speed of electrons
(d) Increase the speed of electrons

8. In a working nuclear reactor, cadmium rods (control rods) are used to
(a) Speed up neutrons (b) Slow down neutrons
(c) Absorb some neutrons (d) Absorb all neutrons

9. Fusion reaction takes place at 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

DIRECTIONS (Q. 10) : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

10. The heavier nuclei tend to have large N/Z ratio, because
(a) Coulomb forces have longer range compared to the nuclear forces
(b) a neutron doesnot exert electric repulsion
(c) a neutron is an unstable particle
(d) a neutron is heavier than a proton

DIRECTIONS (Q. 11) : *Following question has statements (A, B, C and D) given in Column I and statements (p, q, r and s) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

11. Match the following

Column – I	Column – II
(A) Hydrogen bomb	(p) Fission
(B) Atom bomb	(q) Fusion
(C) Stellar energy	(r) Critical mass
(D) Nuclear reactor	(s) Controlled chain reaction

	A	B	C	D
(a)	r	p	s	q
(b)	s	q	r	p
(c)	q	p	r	s
(d)	p	q	s	r

DIRECTIONS (Q. 12) : *Following are integer based/Numeric based questions. Each question, when worked out will result in one integer or numeric value.*

12. In a nuclear reactor U^{235} undergoes fission liberating 200 MeV of energy. The reactor has 10% efficiency and produces 1000 MW power. If the reactor is to function for 10 year, find the total mass of the uranium required.

SOLUTIONS

Brief Explanations of Selected Questions

1 EXERCISE

Fill in the Blanks :

1. Sun
2. solar cooker.
3. electricity.
4. wind energy
5. kinetic
6. tidal energy
7. geothermal
8. methane, hydrogen, hydrogen sulphide
9. destructive distillation.
10. biomass
11. H_2, CH_4 and CO
12. natural gas

True / False :

1. True	**2.** True	**3.** False	**4.** False
5. False	**6.** True	**7.** True	**8.** True
9. False	**10.** False	**11.** True	**12.** False
13. False	**14.** False	**15.** True	**16.** True

Match the Following :

1. (A) $\rightarrow$ q; (B) $\rightarrow$ p; (C) $\rightarrow$ s; (D) $\rightarrow$ t; (E) $\rightarrow$ r; (F) $\rightarrow$ u; (G) $\rightarrow$ w; (H) $\rightarrow$ v

Very Short Answer Questions :

1. CNG gas create less pollution.

2. (i) Methane (ii) Hydrogen.

3. The major constituent of natural gas is methane.

4. Muscular energy to Mechanical energy.

5. Methane is the main constituent of Biogas.

6. (i) Fuel oil has higher calorific value than coal.
(ii) Fuel oil does not leave ash or residue.

7. The traditional use of wind has been modified by using windmills and that of water by constructing hydroelectric power plants.

8. The energy extracted from hot water springs on the earth is called geothermal energy.

9. (i) wind energy (ii) solar energy
These sources of energy can be used again and again endlessly. They will never get exhausted.

10. (i) Fossil fuels (ii) Nuclear fuels
Fossil fuels are present in a limited amount in the earth. Once exhausted, they will not be available to us again.
The nuclear material which can be conveniently extracted from the earth are limited and hence they will get exhausted one day.

11. We would classify energy sources as (a) renewable and non-renewable.
Renewable sources of energy are inexhaustible whereas non-renewable sources of energy are exhaustible. Thus, the options in (a) and (b) are the same.

12. It is a machine for converting the kinetic energy of the fluid (flowing water or gas) into mechanical energy.

13. The energy of water is called hydro energy.

14. The enormous movement of water between the high tides and low tides provides a source of energy, which is called tidal energy.

23. It is a device that cooks food by absorbing solar radiations.

24. Infra-red radiations.

25. It is a device used to supply hot water using sunlight.

Long Answer Questions :

3. The energy of water (or hydro-energy) is in fact an indirect source of solar energy because it is the solar energy which is responsible for water cycle. The heat of solar energy evaporates water from ocean and the surface of the earth. The water vapours rise high in the atmosphere, get cooled and fall back to the earth. The water vapours rise high in the atmosphere, get cooled and fall back to the earth in the form of rain and snow. The rain water and the water formed by melting of snow then flows rapidly in the rivers and provides us with hydro energy.

4. (a) Anaerobic decomposition : The process in which the complex compound of cow dung slurry decomposes or breaks down in the absence of oxygen by anaerobic micro-organisms called anaerobic bacteria is known as anaerobic decomposition.
It generates gases like methane (75%), carbon dioxide, hydrogen and hydrogen sulphide.

Steps involved in obtaining biogas :

(i) Slurry is made by mixing of animal dung with an equal amount of water.
(ii) Slurry is passed through an inlet chamber of an underground digester tank.
(iii) In digester tank, slurry is decomposed by anaerobic bacteria in about 50-60 days to produce biogas.
(iv) The biogas collected in domes built over the digester tank and has a gas outlet with value.
(v) The pressure exerted by the biogas on the slurry forces the spent slurry to the overflow tank via outlet chamber.

(vi) The spent slurry is periodically removed and used as a good manure.
(vii) The whole process is repeated again for regular supply of biogas.

(b) $^{235}_{92}U$ can undergo fission readily.

5. The energy of water (or hydro-energy) is in fact an indirect source of solar energy because it is the solar energy which is responsible for water cycle. The heat of solar energy evaporates water from ocean and the surface of the earth. The water vapours rise high in the atmosphere, get cooled and fall back to the earth. The water vapours rise high in the atmosphere, get cooled and fall back to the earth in the form of rain and snow. The rain water and the water formed by melting of snow then flows rapidly in the rivers and provides us with hydro energy.

6. Solar energy is responsible for wind to blow. The intensity of sun-rays is much more stronger near the equator of the earth than in the polar region. Due to more intense heat, the air near the surface of the earth in equatorial regions become quite hot. The hot air being lighter rises upward and cooler air from the polar region of earth starts flowing which causes wind to blow from the high pressure to low pressure region. So wind blows to equatorial regions. The energy possessed by this wind is called wind energy.

7. Biogas. The gas produced by the decay of biomass in the presence of water by anaerobic micro-organisms in the absence of oxygen is called biogas. Biogas can be obtained by using fixed dome type biogas plant.

The burning of cow-dung cakes is not advisable because of the following reasons :

(i) It produces a lot of ash as residue.
(ii) It produces a lot of smoke causes air pollution as well as creates health hazards.
(iii) It has low heat efficient fuel.
(iv) It destroys the useful manure.

Whereas during the production of biogas only organic matter is decomposed by anaerobic bacteria and convert into biogas. So use of biogas obtained from cow dung advised in preference gives (i) a clean fuel, free from pollution and (ii) spent slurry can be used as a manure.

8. Three forms of oceanic energy are
(a) Sea wave energy
(b) Tidal energy
(c) Ocean thermal energy.

OTEC power plant. The plants which are used to harness ocean thermal energy is called OTEC power plant.

Working of OTEC power plant. A temperature difference between warm surface water heated by sun and colder water at deeper level upto 1000 m is 20ºC or more is required to operate OTEC plant.

In the OTEC system, the warm surface water is used to boil a liquid like ammonia. The vapour of liquid is then used to rotate the turbine of a generator. The cold water from the deeper level is used to convert the ammonia vapour again into liquid.

9. Construction. It consists of an insulated metal box which is painted all black from inside. There is thick glass sheet as a cover over the box and a plane mirror reflector attached to the box.

Cooking of food. The food to be cooked is placed in a metal container kept in the box and covered with glass sheet. When solar energy falls on reflector, the reflector sends them to the top of solar cooker in the form of strong beam of sunlight which is absorbed by the black surface in the box. The infra-red rays cause heating effect which raises the temperature to 100ºC–140ºC which cooks the food.

10. (i) Renewable sources of energy are those that can be used without depleting their reserves and do not get exhausted e.g., solar energy, wind energy, hydro energy, etc.

Non-renewable sources of energy are those which cannot be replenished and exhausted with the passage of time. e.g., : coal, petroleum and natural gas.

(ii) Wood is not advisable used as a fuel, although forests can be replenished, due to the following reasons :
(a) Burning of wood causes pollution.
(b) The left-over residue after combustion have a disposed off problem.
(c) Smoke produced by burning of wood causes health hazard.
(d) Wood is a less heat generating fuel.
(e) Trees are essential for our life as they absorb CO_2 and give out O_2.

2 EXERCISE

Text-Book Questions :

1. A good source of energy has the following characteristics:
(i) It could do a large amount of work per unit volume of mass.
(ii) It should be easily accessible.
(iii) It should be easy to store and transport.
(iv) It should be economical.

2. (a) It should have high calorific value.
(b) It should have low ignition temperature.
(c) It should not leave more ashes.

(d) It should not produce harmful gases on burning.
(e) It should be economic and easy to handle.

3. If we are in a rural area, gobar-gas or biogas should be used as they are easily available there and are almost pollution free. Also, they have high calorific value.
In a city, LPG should be used since it doesn't produce pollution, it is easily available and economical than other sources.

4. (i) They are formed under the earth's surface by a long process which takes million of years to form.
(ii) It is non-renewable source of energy.
(iii) They cause air pollution

5. Because of our changing life style and new technology we want more efficient fuels which are pollution free, cheap and renewable which cannot be fulfilled by using traditional sources of energy.

6. (i) Wood is converted into charcoal by destructive distillation of wood which is a better fuel than wood. Use of charcoal is also ecofriendly because it causes very less pollution and leaves less residue on burning.
(ii) Use of water energy needs the construction of big dams. These dams are being constructed near to a big river and it is more expensive. To improve the efficiency of water energy, the technology is being developed to increase the efficiency of devices used to convert water energy into electrical energy.

7. Plane mirror is best suited for a solar cooker because it reflects the parallel rays of sunlight to the top of solar cooker box in the form of a strong beam of sunlight, which helps the food to cook fast.

8. The energy from the ocean can be obtained mainly in three forms- (i) tidal energy (ii) wave energy and ocean thermal energy. But these energy can't be a potential source of energy in future because of the following reasons –
(i) there are very few places around the world which are suitable for building tidal dams.
(ii) the rise and fall of sea-water during high and low tides is not enough to generate electricity on a large scale.

9. **Geothermal energy :** It is a form of heat energy which is available under the earth's crust. Temperature, inside the earth's crust in the deeper levels is high as compared to temperature near the surface of earth i.e. as depth increases temperature also increases. Due to this heat, rocks melt to form hot magma and heat starts flowing from deeper levels to upper levels due to which heat gets collected at some depth below the earth's surface. Such places are known as hot spots. These hot spots are the main source of geothermal energy. Water in contact with these hot spots turns into steam which can be utilised to generate electricity.

10. (i) It doesn't produce gases like carbon dioxide and sulphur dioxide which contribute to pollution.
(ii) It produces a large amount of useful energy from a very small amount of nuclear fuel.
(iii) The nuclear fuel (like U-235), once kept in nuclear power plants, produce electricity for a long time.

11. No source of energy is absolute pollution free. But hydro-energy, bio-mass energy, wind-energy, solar energy, etc. are almost pollution free.

12. Hydrogen is a cleaner fuel than CNG because :
(i) Hydrogen has high calorific value than CNG.
(ii) CNG is conventional source of energy but H_2 is not.
(iii) CNG is green house gas but H_2 is not.
(iv) Burning of CNG gives out CO and CO_2 gases but burning of H_2 does not give any such harmful gases.

13. Solar energy and wind energy are two kinds of renewable energy whose sources are the sun and the wind. Both of these sources are available everywhere and can be used to produce other forms of energy like electric energy.

14. Coal and petroleum are two exhaustible sources of energy. Both are the reserve inside the earth which are in a limited amount and can exhaust after some days if it will be used at present rate.

Text-Book Exercise :

1. (b) a cloudy day. **2.** (c) Nuclear energy
3. (a) Geothermal energy
4. **Comparision :**
(i) Both are widely used sources of energy
(ii) Both are natural sources.
Contrast :

Fossil Fuels	Sun
(i) It is a conventional source of energy	(i) It is a non conventional source of energy
(ii) It is in a limited quantity	(ii) Energy provided from Sun is very large or unlimited
(iii) They can be used at any time	(iii) Solar energy can be used only in day time & on a sunny day.
(iv) It causes air pollution	(iv) Solar energy does not cause air pollution.
(v) It costs to buy fossil fuel	(v) It is free of cost.

5. **Comparision :**
(i) Both are non-conventional sources of energy.
(ii) Working cost of both sources is very low.
Contrast :

Biomass	Hydroelectricity
(i) It is a renewable source of energy	(i) It is a non renewable source of energy.
(ii) It possesses chemical energy	(ii) It possesses kinetic energy of running water at high altitudes.
(iii) It causes air pollution	(iii) It does not cause air pollution.
(iv) Biomass is relatively more economical source of energy.	(iv) It is costly source as compared to biomass.

6. Limitation of extracting energy from
   (i) Wind : (a) Everywhere and any time the flowing air is not available.
   (b) To generate electricity the wind should have speed more than 15 km / h.
   (ii) Waves: (a) The wave is not available source of energy to generate electricity.
   (b) It is costly to set up device to trap wave energy.
   (iii) Tides: (a) The location for constructing dam for harnessing tide are limited.
   (b) Construction of dams is a very costly setup.
7. (a) If the source of energy can be converted back to its original form after extracting energy, then it is said to be renewable source of energy e.g., hydroelectricity. If the source of energy cannot be converted back into its original form. It is said to be non renewable source of energy, e.g., coal and petroleum.
   (b) Sources of energy that will not exhaust in significant time are called inexhaustible sources, e.g., Sun, water, etc. Sources of energy that will exhaust in reasonable time are called exhaustible source e.g., coal.
   Renewable sources of energy produce inexhaustible energy whereas non-renewable sources produce exhaustible energy.
8. (i) It should give large amount of work per unit volume or mass of fuel.
   (ii) It should be easily accessible.
   (iii) It should be easy to store and transport.
   (iv) It should be economical.
9. **Advantages :**
   (i) It cooks food without causing any pollution.
   (ii) It is economical to use a solar cooker.
   (iii) It is easy to handle a solar cooker.
   (iv) The nutrients of food do not get destroyed.
   Disadvantages :
   (i) It cannot be used at night and in cloudy day.
   (ii) It takes more time to cook food.
   (iii) The direction of solar cooker is to be changed continuously towards the direction of sun.
   (iv) Solar energy is not available at all time and at all the place
   (v) It cannot be used for baking and frying purpose.
   At south pole, sunlight doesn't reach. Therefore, a solar cooker cannot be utilised at this place.
10. Affluent life style and industrialisation have increased the demand of energy. Consequences are given below -
   (i) The increase of demand can make excessive exploitation of sources of energy which disturbs the environmental balance.
   (ii) The increase of demand makes excessive use of conventional sources of energy. Thus, energy crisis in future may be caused.
   Following steps can be suggested to reduce the energy consumption -
   (i) Misuse of energy should be avoided.
   (ii) Renewable sources of energy, such as solar energy, tidal energy, etc., should be used.
   (iii) Pollution free sources of energy should be used.
   (iv) Best possible technology should be made available. For example, smokeless chullas should be preferred to traditional chullas.

Exemplar Questions :

1. Air pollution, Green house effect, Environment consequences: Acid rain, global warming etc. Steps: Use of smokeless appliances, Refined technology, Judicious use of energy etc.
2. (i) Our demand for energy is increasing to improve quality of life and growth of population.
   (ii) Fossil fuels are limited.
3. Plane mirror acts as a reflector.
   Glass sheet results in green house effect.
4. (i) Solar cells have no moving parts
   (ii) Requires little maintenance
   (iii) They can be set up in remote areas
5. Because of it being erratic, energy cannot be harnessed continuously. Large areas are required for wind farms.
6. (i) Fossil fuels are depleting. Population is increasing, Quality of life is to be improved etc.
   (ii) Tidal/wave/OTEC

Hots Questions :

2. (i) Find q (i.e.,) 1% of 10^8J. This is the solar energy that is converted to wood in one day.
   Find the amount of heat energy liberated on burning 50 kg of wood by using the formula,
   $Q = mS$ .... (1) where S is the calorific value of wood.
   Then, find the number of days required to produce 50 kg of wood by using formula,
   $Q = nq = mS$ ....(2)
   (ii) 750 days
3. (i) Find the amount of water (m) flows in one day.
   Let the volume of water that flows in every minute = V.
   (ii) Density of water (d) = $\frac{m}{V}$
   (iii) One day = 24×60 minutes
   (iv) Mass of the water that flows in one day is $m = Vd \times (60 \times 24)$
   (v) Potential energy, PE = mgh
   (vi) The energy of the flowing water in one day is = mgh

(vii) 60% of the (mgh) is used to generate electricity

(viii) 24×10^3 kW h or 24 MW h

4. CH_4 is a better fuel.

5. (i) Find the amount of heat (Q) required to boil given water by using Q = ms (Δt).

(ii) The above value of Q is only 70% of the amount of heat liberated by combustion of fuel (Q^1)

(iii) Then the mass of the fuel combusted is, $m_{fuel} = \frac{Q^1}{S}$

(iv) 76 g

6. (i) The volume of air that makes blades to rotate = V = ℓ × area of the blade

(ii) Velocity (v) = $\frac{\ell}{t}$

(iii) Mass of the air = m = volume × density of air

(iv) Kinetic energy (KE) of air = $\frac{1}{2}mv^2$

(v) 50% of kinetic energy of air is converted into electrical energy (EE)

(vi) The power of electrical generation is, $P = \frac{EE}{1s}$

(vii) 2.53 kW

9. (i) It is because a piece of fresh wood is not dry and therefore it is to be heated at high temperature before it catches fire, that is why it is difficult to burn.

(ii) It cuts off the supply of air (oxygen) which is required for combustion to take place.

(iii) Hydrogen is highly combustible and burns with an explosion, therefore, it is difficult to store and transport.

(iv) Charcoal, has higher calorific value than wood and produces less smoke than wood.

10. Major fuel component of biogas–Methane. Other combustile component of biogas–Hydrogen, Hydrogen sulphide, Carbon dioxide.

Use of residue slurry. Left-over slurry from the biogas plant is used as a manure because it is rich in nitrogen and phosphorus compounds and can be used in place of nitrogeneous and phosphorus fertilizers.

11. Cause of wind to blow. Unequal heating of the different land mass and water bodies such as river, lake, ocean etc. by solar radiations creates a different pressure regions. The flow of air from higher pressure region i.e., polar region towards the lower pressure region i.e., equatorial region, constitutes wind.

It is Kanya Kumari in Tamil Nadu where wind energy is commercially harnessed.

Wind power potential. From the wind power India generates only 2000 MW whereas India has the potential to generate 45000 MW of electrical power from wind energy.

Hydro power potential. It is estimated that India can generate about 4×10^{11} kWh of electricity when its hydro power potential is fully exploited. At present, India can exploit only 11% of its potential capacity.

Drawbacks of wind power plant.

(i) Wind is not available at all the places all the time.

(ii) Establishment of wind energy requires large area and huge structure of windmill which increase the cost.

Drawbacks of hydro power plant.

(i) The imbalance in ecosystem over a long period of time.

(ii) Conversion efficiency of water energy into electrical energy is very low.

3 EXERCISE

Single Option Correct :

1.	(c)	**2.**	(b)	**3.**	(a)	**4.**	(b)	**5.**	(b)
6.	(c)	**7.**	(a)	**8.**	(c)	**9.**	(a)	**10.**	(b)
11.	(b)	**12.**	(a)	**13.**	(d)	**14.**	(b)	**15.**	(c)
16.	(b)	**17.**	(d)	**18.**	(a)	**19.**	(c)	**20.**	(c)
21.	(d)	**22.**	(a)	**23.**	(a)	**24.**	(b)	**25.**	(a)
26.	(a)	**27.**	(c)	**28.**	(a)	**29.**	(c)	**30.**	(b)
31.	(c)	**32.**	(c)	**33.**	(b)	**34.**	(c)	**35.**	(c)
36.	(a)	**37.**	(d)	**38.**	(d)	**39.**	(d)	**40.**	(d)
41.	(d)	**42.**	(b)	**43.**	(a)	**44.**	(b)	**45.**	(a)
46.	(a)	**47.**	(b)	**48.**	(b)	**49.**	(a)	**50.**	(b)
51.	(d)	**52.**	(c)	**53.**	(b)	**54.**	(a)		

More Than One Option Correct :

1. (a, c, d) **2.** (a,b,d) **3.** (a,c,d) **4.** (b,c,d)

5. (a,c,d) **6.** (a,b,d)

Assertion & Reason :

1. (b) **2.** (a) **3.** (a)

Multiple Matching Questions :

1. (d)

Integer/ Numeric Questions :

1. Here, mass of fuel, m = 1 kg = 1000 g

Calorific value, c = 15 kJ/g

Energy yielded, Q = ? (to be calculated)

From relation, Q = mc

putting value, we get, Q = 1000 × 15 kJ

= 15000 kJ.

2. Heat received per day, Q' = 10^8 J per day

= 10^5 kJ per day

Efficiency of conversion, $\eta = 1\% = 0.01$

Mass of wood to be produced, $m = 10 \text{ kg} = 10^4 \text{ g}$
Calorific value of wood, $c = 15$ kJ/g
Number of days required, N = ? (to be calculated)
From relation, total energy required, $Q = mc$

Putting values, we get, $Q = 10^4 \times 15$ kJ

$= 15 \times 10^4$ kJ
It is 1% of the total solar energy incident.

Total energy incident, $Q_{Total} = \dfrac{Q}{\eta}$

Putting values, we get, $Q_{Total} = \dfrac{15 \times 10^4}{0.01}$

$= 15 \times 10^6$ kJ.

From relation, Q_{Total} = Number of days × Heat received per day i.e., $Q_{Total} = NQ'$

We have, $N = \dfrac{Q_{Total}}{Q'}$; Putting values, we get, N =

$$\frac{15 \times 10^6 \text{ kJ}}{10^5 \text{ kJ per day}} = 150 \text{ days}$$

Number of days taken, N = 150 days.

3. $M = 500$ g; $s = 4.2$ J/g/°C; $\Delta T = 70°C - 20°C$ $= 50°$; mass of fuel (X) $= 0.06$ kg $= 60$ gm
$Q = Ms\Delta T = (500 \times 4.2 \times 50)$ J

$$= \frac{(500 \times 4.2 \times 50)\text{J}}{1000} = 105 \text{ kJ}$$

$$CV = \frac{105}{60} = 1.75 \text{ kJ/gm.}$$

4. $X = 10$ gm; $M = 2000$ gm; $\Delta T = 50°C$;
$C = 4.2$ J/kg°C
$Q = MC\Delta T = 2000 \times 4.2 \times 50$ J

$$= \frac{2000 \times 4.2 \times 50}{1000} = 10 \times 42 \text{ kJ}$$

$$CV = \frac{Q}{X} = \frac{10 \times 42}{10} = 42 \text{ kJ/gm}$$

5. $CV = 50$ kJ/gm; $X = 14$ kg. $= 14000$ gm;

$$CV = \frac{Q}{X}$$

$Q = CV \times X = 50 \times 14000$ kJ
Energy consumed in 30 days = 7,00,000 kJ

Energy consumed in 1 day $= \dfrac{7{,}00{,}000}{30}$ kJ

$= 23333.33$ kJ/day.

6. $CV = 45$ kJ/gm.; $X = 10{,}000$ gm

$$CV = \frac{Q}{X} \Rightarrow 45 = \frac{Q}{10{,}000} \Rightarrow Q = 4{,}50{,}000 \text{ kJ}$$

Energy consumed in 30 days = 4,50,000 kJ

Energy consumed in 1 day $= \dfrac{4{,}50{,}000}{30}$

$= 15{,}000$ kJ

7. 1 mole of methane = 16 gm
16 gm of methane provides 805 kJ of energy

1 gm of methane provide $= \dfrac{805}{16} = 50.3$ kJ/gm

$CV = 50.3$ kJ/gm.

8. $CV = 50$ kJ/gm; $M = 2$ kg;
$s = 4200$ J/kg/°C; $\Delta T = 40°C$
$Q = Ms\Delta t = 2 \times 4200 \times 40$ J

$$= \frac{2 \times 4200 \times 40}{1000} \text{ kJ} = 42 \times 8 \text{ kJ}$$

$$CV = \frac{Q}{X} \Rightarrow 50 = \frac{42 \times 8}{X};$$

$$X = \frac{42 \times 8}{50} = \frac{168}{25} = 6.72 \text{ gm.}$$

9. $E = mc^2 = (1.66 \times 10^{-27})(3 \times 10^8)^2$ joule
$= 1.49 \times 10^{-10}$ J

$$= \frac{1.49 \times 10^{-10}}{1.6 \times 10^{-13}} \text{ MeV} = 931.49 \text{ MeVs}$$

10. Energy obtained per fission = 200 MeV
$= 200 \times 1.6 \times 10^{-13}$ J $= 3.2 \times 10^{-11}$ J
No. of fission per second required

$$= \frac{2 \times 10^6}{3.2 \times 10^{-11}} = 6.25 \times 10^{16}$$

11. Mass defect $\Delta m = 2 \times 2.01471 - 4.00388$
$= 0.02554$ amu
Energy liberated $= 0.02554 \times 931.5$ MeV
$= 23.79$ MeV

12. Mass of reactants = $6.015126 + 1.0086654$
$= 7.0237914$ amu
Mass of products = $4.0026044 + 3.016049$

$= 7.0186534$ amu

Difference in mass= $7.0237914 - 7.0186534$

$= 0.0051380$ amu

Energy corresponding to mass difference

$= 0.005138 \times 931$

$= 4.78$ MeV.

4 ADVANCED EXERCISE
BASED ON CONNECTING TOPICS

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

10. (a,b)

11. (c)

12. If m kg is the required mass of the uranium, then number of nuclei

$$= \frac{(m \times 1000) \times 6.02 \times 10^{23}}{235}$$

Each U^{235} nucleus releases energy 200 MeV,

$\therefore$ total energy released in 10 years

$$E_{in} = \frac{m \times 6.02 \times 10^{26}}{235} \times 200$$

Energy required in 10 years, E_{our}= Pt

$=(1000 \times 10^6) \times (10 \times 365 \times 24 \times 3600)$

Efficiency $\eta = \frac{E_{out}}{E_{in}}$

Substituting the values, we get

$$m = 3.8 \times 10^4 \ kg.$$

Chapter 6

STATIC ELECTRICITY

INTRODUCTION

Electricity is the cause of something present in matters called the 'electric charge'. Although charges are present in all matters but all of them do not produce electricity. Actually, electricity is produced by those matters which are 'electrically charged' or by charges in motion. The electricity produced by charges at rest is known as electrostatics or static electricity and the electricity produced by charges (electrons) in motion is called 'current electricity'. Static electricity can only be generated in insulators e.g., glass, plastic, rubber etc.

This chapter deals with the electricity produced by charges at rest. A static charge can produce an electric field but it cannot produce an electric current. Electric current can be produced only when the charges are in motion. Electric charges can be stored and used as per requirement. The device which stores charges is known as 'capacitor'.

ELECTRIC CHARGE

Charge is something associated with matter due to which it produces and experiences electric and magnetic field.

There are two types of charges.

(i) Positive charge (due to loss of electrons) (ii) Negative charge (due to excesss of electrons)

Charge on one electron e = – 1.6 × 10^{-19} coulomb.

When there is neither an excess nor a lack of electrons the body is uncharged.

We know that mass is responsible of gravitational force. Similarly, there is a property to every massive object which is responsible for another kind of force which can be attractive or repulsive unlike gravitational force which is only attractive. Also, this force is much more stronger than gravitational force. This force is termed as electrical force. So, charge is responsible for electrical forces.

Electric eel. (Electrophorus electricus) is an electrical fish which is capable of generating powerful electric shocks of up to 600 volts in order to stun prey and keep predators at bay. Up to 6,000 electroplates are arranged like a dry cell in the eel's body. Its internal organs are all in a small area behind the head, with 7/8 of the eel being tail. The electrical shocks come from muscles mainly in the tail portion of the electric eel's body. The body of an electric eel is similar to a battery.
The tail end of the eel has a positive charge and the head region is negatively charged. When the eel touches its tail and head to other animals it sends electric shocks through their bodies. When the eel is at rest, there is no generation of electrical impulses.

Fig. 6.1 : Electric eel

HISTORICAL PREVIEW

It was discovered centuries ago that certain types of materials would mysteriously attract one another after being rubbed together. For example: after rubbing a piece of silk against a piece of glass, the silk and glass would tend to stick together. Indeed, there was an attractive force that could be demonstrated even when the two materials were separated.

Glass and silk aren't the only materials known to behave like this. Anyone who has ever brushed up against a latex balloon only to find that it tries to stick to them has experienced this same phenomenon. Paraffin wax and wool cloth are another pair of materials early experimenters recognized as manifesting attractive forces after being rubbed together.

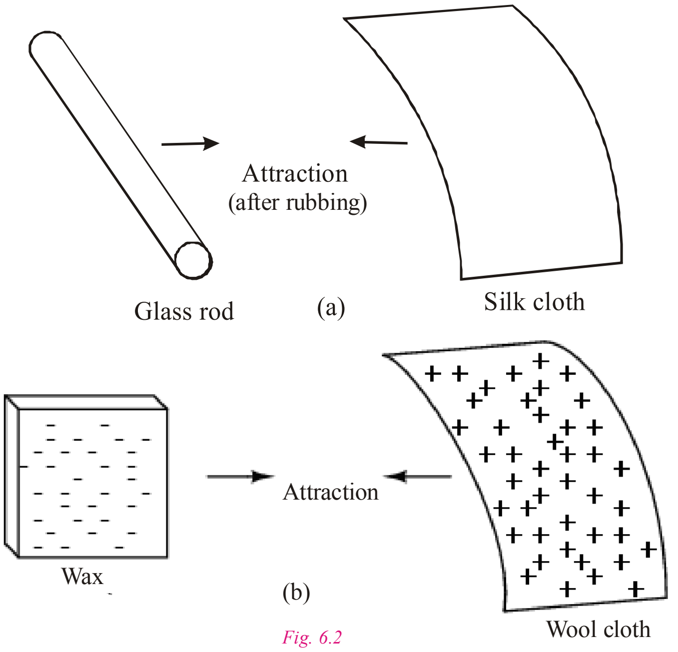
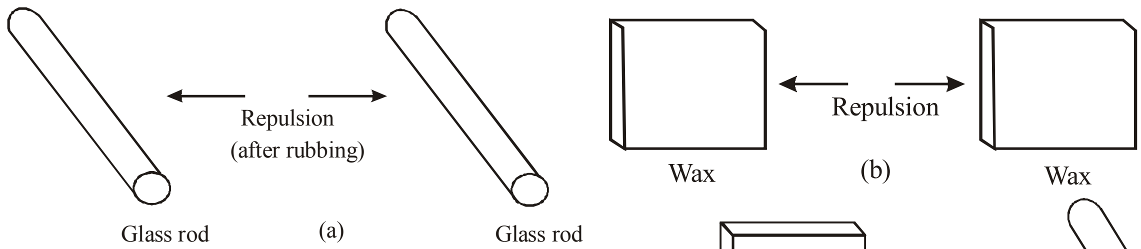


Fig. 6.2

This phenomenon became even more interesting when it was discovered that identical materials, after having been rubbed always repelled each other.



It was also noted that when a piece of glass rubbed with silk was exposed to a piece of wax rubbed with wool, the two materials would attract one another.

Furthermore, it was found that any material demonstrating properties of attraction or repulsion after being rubbed could be classed into one of two distinct categories: attracted to glass and repelled by wax, or repelled by glass and attracted to wax. It was either one or the other: there were no materials found that would be attracted to or repelled by both glass and wax, or that reacted to one without reacting to the other.

More attention was directed toward the pieces of cloth used to do the rubbing. It was discovered that after rubbing two pieces of glass with two pieces of silk cloth, not only did the glass pieces repel each other, but so did the cloths. The same phenomenon held for the pieces of wool used to rub the wax.

Now, this was really strange to witness. After all, none of these objects were visibly altered by the rubbing, yet they definitely behaved differently than before they were rubbed. Whatever change took place to make these materials attract or repel one another was invisible.

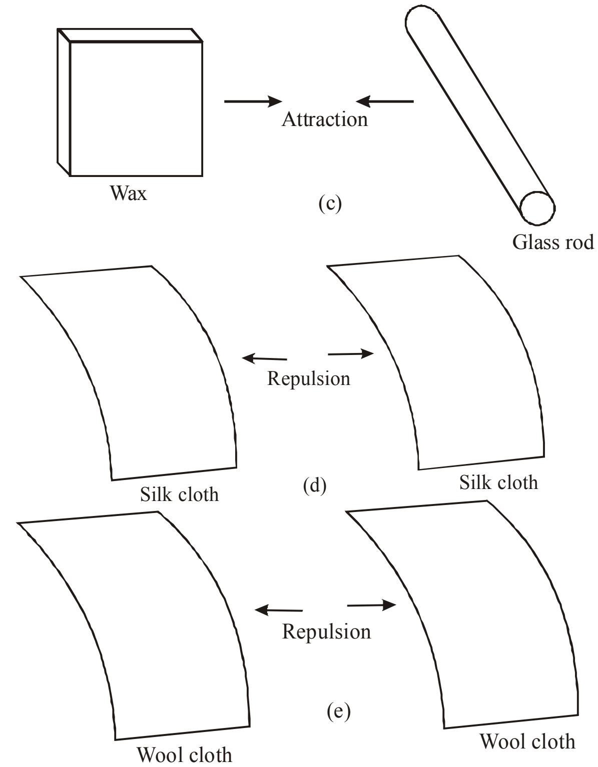


Fig. 6.3

Some experimenters speculated that invisible "fluids" were being transferred from one object to another during the process of rubbing, and that these "fluids" were able to effect a physical force over a distance. Charles Dufay was one the early experimenters who demonstrated that there were definitely two different types of changes brought by rubbing certain pairs of objects together. The fact that there was more than one type of change manifested in these materials was evident by the fact that there were two types of forces produced: attraction and repulsion. The hypothetical fluid transfer became known as a charge.

One pioneering researcher, **Benjamin Franklin,** came to the conclusion that there was only one fluid exchanged between rubbed objects, and that the two different "charges" were nothing more than either an excess or a deficiency of that one fluid. After experimenting with wax and wool, Franklin suggested that the coarse wool removed some of this invisible fluid from the smooth wax, causing an excess of fluid on the wool and a deficiency of fluid on the wax. The resulting disparity in fluid content between the wool and wax would then cause an attractive force, as the fluid tried to regain its former balance between the two materials.

Postulating the existence of a single "fluid" that was either gained or lost through rubbing accounted best for the observed behavior: that all these materials fell neatly into one of two categories when rubbed, and most importantly, that the two active materials rubbed against each other always fell into opposing categories as evidenced by their invariable attraction to one another. In other words, there was never a time where two materials rubbed against each other both became either positive or negative.

Following Franklin's speculation of the wool rubbing something off of the wax, the type of charge that was associated with rubbed wax became known as "negative" (because it was supposed to have a deficiency of fluid) while the type of charge associated with the rubbing wool became known as "positive" (because it was supposed to have an excess of fluid). Little did he know that his innocent conjecture would cause much confusion for students of electricity in the future.

Precise measurements of electrical charge were carried out by the French physicist Charles Coulomb in the 1780's using a device called a torsional balance measuring the force generated between two electrically charged objects. The results of Coulomb's work led to the development of a unit of electrical charge named in his honor, the coulomb. If two "point" objects (hypothetical objects having no appreciable surface area) were equally charged to a measure of 1 coulomb, and placed 1 meter (approximately 1 yard) apart, they would generate a force of about 9 billion newtons (approximately 2 billion pounds), either attracting or repelling depending on the types of charges involved.

It was discovered much later that this "fluid" was actually composed of extremely small bits of matter called electrons, so named in honour of the ancient Greek word for amber: another material exhibiting charged properties when rubbed with cloth. Experimentation has since revealed that all objects are composed of extremely small "building-blocks" known as atoms, and that these atoms are in turn composed of smaller components known as particles. The three fundamental particles comprising atoms are called protons, neutrons, and electrons.

The result of an imbalance of this "fluid" (electrons) between objects is called static electricity. It is called "static" because the displaced electrons tend to remain stationary after being moved from one material to another.

ACTIVITY :

Take any two materials from the following list and then rubbed with each other.

Fur $\rightarrow$ glass $\rightarrow$ paper $\rightarrow$ metal $\rightarrow$ silk $\rightarrow$ plastic $\rightarrow$ amber $\rightarrow$ rubber $\rightarrow$ sulpur

We can always find that the former one is positively charged and the later one is negatively charged.

When a charged body is close enough to a neutral body, they attract each other.

One of the applications of this effect is to use tiny paint droplets to paint the automobiles uniformly.

CHECK Point

When one material is rubbed against another, electrons jump readily from one to the other, but protons do not. Why is this? (Think in atomic terms.)

SOLUTION

Protons are bound with the nucleus of an atom but electrons revolve round it. Therefore, electrons can easily be dislodged from an atom but it is difficult to take out a proton from the atom. This is why, when one material is rubbed against another, electrons jump readily from one to the other, but protons do not.

PROPERTIES OF CHARGES

1. **Charge is conserved :** That is, net charge can neither be created nor destroyed. Note the term net charge. Although charges can be created or destroyed in some processes but the net charge always remains conserved.
2. **Charge is quantized :** Charge on any particle can never be less than the charge of an electron (i.e., $e = -1.6 \times 10^{-19}\, C$).
   In other words, the total charge on any particle is an integral multiple of the charge of electron (e). Let a particle has charge q then
   $$q = \pm ne, \quad \text{where } n = 1, 2, 3, 4, \ldots\ldots.$$
   It means that a charge of $\frac{2}{3}e, \frac{1}{4}e$ or $\frac{4}{5}e$ on any body is not possible as they are not integral multiple of the charge of electron.
3. Unlike charges repel each other and like charges attract each other.
4. A charge at rest produces an electric field in the space around it. A uniformly moving charge produces both electric and magnetic field and a non-uniformly moving charge radiates energy.

ILLUSTRATION : 6.1

Calculate the net charge on a substance consisting of (a) 5×10^{14} electrons (b) a combination of 7×10^{13} protons and 4×10^{13} electrons.

SOLUTION :

(a) The charge of one electron is $-1.6 \times 10^{-19} C$. So net charge on a substance consisting of 5×10^{14} electrons is
$5 \times 10^{14} \times (-1.6 \times 10^{-19} C) = -8 \times 10^{-5} C = -80 \mu C.$

(b) Similarly the net charge on a substance consisting of a combination of 7×10^{13} protons and 4×10^{13} electron is
$[7 \times 10^{13} \times (1.6 \times 10^{-19} C)] + [4 \times 10^{13} (-1.6 \times 10^{-19} C] = +4.8\, \mu C.$
($\because$ the charge on one proton is $+ 1.6 \times 10^{19}$C)

ILLUSTRATION : 6.2

When a piece of polythene is rubbed with wool, a charge of -2×10^{-7} *C* is developed on polythene. What is the amount of mass, which is transferred to polythene?

SOLUTION :

No. of electrons transferred, $n = \frac{q}{e}$

Mass transferred $= m_e \times n = m_e \times \left(\frac{q}{e}\right) = 9.1 \times 10^{-31} \times \left(\frac{2 \times 10^{-7}}{1.6 \times 10^{-19}}\right) = 11.38 \times 10^{-19}$ kg

CONDUCTORS AND INSULATORS

Suppose you charge a rubber rod and then touch it to a neutral object. Some charge, repelled by the negative charge on the rod, will be transferred to the originally-neutral object. What happens to that charge then depends on the material of which the originally-neutral object consists. In the case of some materials, the charge will stay on the spot where the originally neutral object is touched by the charged rod. Such materials are referred to as insulators.

i.e., *materials through which charge cannot move, or, through which the movement of charge is very limited are called insulators*. Examples of good insulators are quartz, glass, and air.

In the case of other materials, the charge, almost instantly spreads out all over the material, in response to the force of repulsion (recalling that force causes acceleration which leads to the movement) that each elementary particle of the charge exerts on every other elementary particle of charge.

Materials in which the charge is free to move about are referred to as conductors. Examples of good conductors are metals and saltwater.

When you put some charge on a conductor, it immediately spreads out all over the conductor. The larger the conductor, the more it spreads out. In the case of a very large object, the charge can spread out so much that any chunk of the object has a negligible amount of charge and hence, behaves as if were neutral. Near the surface of the earth, the earth itself is large enough to play such a role. If we bury a good conductor such as a long copper rod or pipe, in the earth, and connect to it another good conductor such as a copper wire, which we might connect to another metal object, such as a cover plate for an electrical socket, above but near the surface of the earth, we can take advantage of the earth's nature as a huge object made largely of conducting material. If we touch a charged rubber rod to the metal cover plate just mentioned, and then withdraw the rod, the charge that is transferred to the metal plate spreads out over the earth to the extent that the cover plate is neutral. We use the expression "the charge that was transferred to the cover plate has flowed into the earth." A conductor that is connected to the earth in the manner that the cover plate just discussed is connected is called "ground." The act of touching a charged object to ground is referred to as grounding the object. If the object itself is a conductor, grounding it (in the absence of other charged objects) causes it to become neutral.

METHODS OF CHARGING AN UNCHARGED BODY

By Induction: When a charged particle is taken near to neutral metallic object then the electrons move to one side and there is excess of electrons on that side making it negatively charged and deficiency on the other side making that side positively charged. Hence charges appear on two sides of the body (although total charge of the body is still zero). This phenomenon is called induction and the charge produced by it is called induced charge.

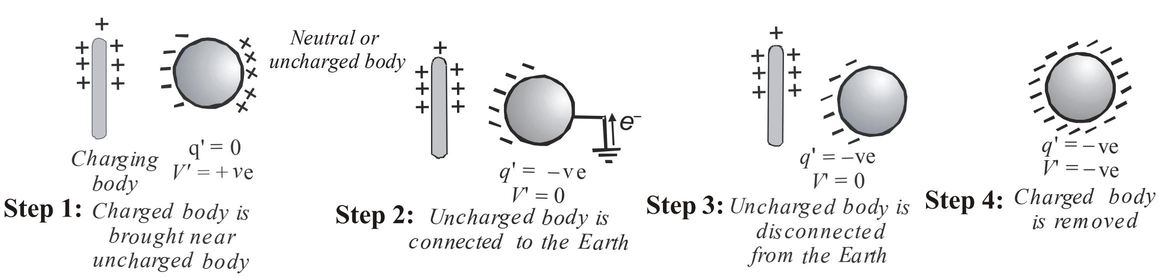


Fig. 6.4

Friction or rubbing, conduction, thermionic ionisation, photoelectric effect and field emission are some other methods of charging a body.

COULOMB'S LAW

The force exerted by one *point charge* (when separation between charged bodies is much larger than their linear sizes) on another, acts along the line joining the two charges, it varies inversely as the square of the distance separating the charges and is proportional to the product of the charges. The force depends on the medium. The force is repulsive if the charges have the same sign and attractive if the charges have opposite signs.

The magnitude of the electric force exerted by a charge q_1 on another charge q_2 a distance r away is thus given by

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

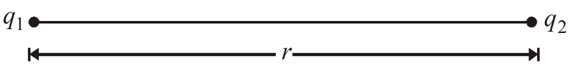


Fig. 6.5

Where k is an experimentally determined constant called the Coulomb constant, which has the value

$$k = 8.99 \times 10^9\,\text{Nm}^2/\text{C}^2 \simeq 9\times10^9\,\text{Nm}^2/\text{C}^2$$

If q_1 is at position $\vec{r}_1$ and q_2 is at $\vec{r}_2$, the force $\vec{F}_{1,2}$ exerted by q_1 on q_2 is

$$\vec{F}_{1,2} = \frac{kq_1q_2}{r_{1,2}^2}\hat{r}_{1,2}$$

Where $\vec{r}_{1,2} = \vec{r}_2 - \vec{r}_1$ is the vector pointing from q_1 to q_2, and $\hat{r}_{1,2} = \vec{r}_{1,2}/r_{1,2}$ is a unit vector pointing from q_1 to q_2.

It is common practice to express k in terms of another constant ε_0, by writing $k = 1/(4\pi\varepsilon_0)$; ε_0 is called the **permittivity of free space** or **absolute electrical permittivity** and has a value of $\varepsilon_0 = 1/(4\pi k) = 8.85 \times 10^{-12}\ C^2/(Nm^2)$.

If some dielectric (insulator) is present in the space between the charges, the net force acting on each charge is altered. The force decreases k times if the medium extends till infinity. Here k is a dimensionless constant which depends on the medium and called dielectric constant of the medium. Thus

$$F_e = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q_1q_2}{r_2} \quad \text{or} \quad F_e' = \frac{F_e}{k} = \frac{1}{4\pi\varepsilon_0 k}\cdot\frac{q_1q_2}{r_2} = \frac{1}{4\pi\varepsilon}\cdot\frac{q_1q_2}{r^2}$$

Here, $\varepsilon = \varepsilon_0 k$ is called permittivity of the medium.

For vacuum or air $K = 1$, for water $k = 80$, for mica $k = 7$ to 10

CHECK Point

How does the magnitude of electric force compare with the charge between a pair of charged particles when they are brought to half their original distance of separation? To one-quarter their original distance? To four times their original distance? (What law guides your answers?)

SOLUTION

According to inverse-square law, the electric force between two charges is inversely proportional to the square of the distance of their separation. Therefore, when the charges are brought to half their original distance of separation, the electric force between them increases by four times as $F \propto q_1 q_2$.

If the separation distance is made one-quarter their original distance, the force increases by sixteen times as $F \propto \frac{1}{r^2}$.

Similarly, the force between the charges decreases by sixteen times when the separation distance between them is made four times their original distance.

(The inverse square law guides our answer).

ILLUSTRATION : 6.3

Three identical point charges are placed at the corners of an equilateral triangle. If the electrostatic force between the any two charges is F, then find the net electrostatic force on the each one.

SOLUTION :

Three identical points charges, say, positive and having magnitude q, are placed at the corners of an equilateral triangle, as shown. The charge at the top corner experiences two electrostatic repulsive forces F, F due to the other two charges. Then, the net electrostatic force on this charge becomes.

$$F' = \sqrt{F^2 + F^2 + 2F \times F \cos 60^\circ}$$

$$= F\sqrt{3}$$

and acts in direction perpendicular to the base of triangle, as shown

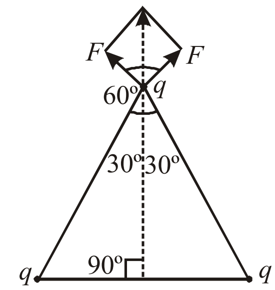


Fig. 6.6

ILLUSTRATION : 6.4

Tow points charges $q_1 = +2C$ and $q_2 = -1C$ are separated by a distance r. Then, define the position of a third point charge $q_3 = +1C$ in the equilibrium on the line passing through the two charges.

SOLUTION :

The third charge q_3 must be situated on the line passing through the two charges q_1 and q_2, as shown. This charge experiences a repulsive electrostatic force F_{31} due to q_1 and an attractive electrostatic force F_{32} due to q_2. The forces F_{31} and F_{32} are equal but opposite so that the net electrostatic force on the charge q_3 is zero and hence, it is in the equilibrium.

$$F_{31} = F_{32}$$

$$\Rightarrow \quad \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{2\times 1}{(r+r')^2} = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{1\times 1}{(r')^2}$$

$$\Rightarrow \quad r + r' = \sqrt{2}r'$$

$\Rightarrow \quad r' = \dfrac{r}{(\sqrt{2}-1)}$ which is the distance of q_3 from q_2.

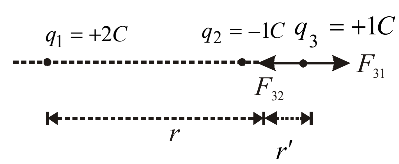


Fig. 6.7

ELECTRIC FIELD

If we place a charge in any region of space, it is observed that any other charge placed in that region experiences a force.

The space around an electric charge in which its influence can be experienced by other charges is called electric field.

The **intensity of electric field** at a point, is defined as the force experienced by a unit positive charge placed at that point. Its direction is in the direction of the electric field if the charge is positive and opposite to it if the charge is negative. It is a vector quantity

Mathematically, $E = \dfrac{F}{q}$, where E = electric field; F = force experienced by charge q.

The **S.I. unit** of electric field is newton per coulomb (N/C).

ILLUSTRATION : 6.5

A particle of mass m and charge $+q$ is placed at rest in a uniform electric field $\vec{E}$, as a shown, and released. Calculate the kinetic energy it gains after moving a distance h.

SOLUTION :

The particle experiences an electric force of magnitude $F = qE$ in the downward direction. This force does a positive work

$W = F \times h = qEh$

on the particle and the particle gains a kinetic energy equal to this work done, when it is released in the electric field and moves dawnwards through the distance h due to the electric force on it.

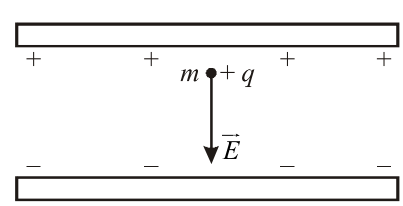


Fig. 6.8

Knowledge ENHANCER

Electric Field due to a Single Point Charge

The electric field $\vec{E}$ at a point P at a distance r due to a single point charge q has the magnitude

$$E=\left(\frac{1}{4\pi\varepsilon_0 K}\right)\left(\frac{q}{r^2}\right) \Rightarrow E \propto \frac{1}{r^2}$$

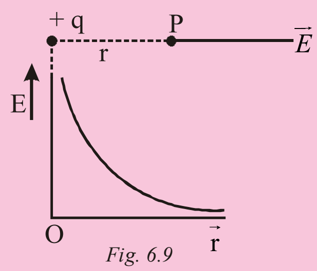


Fig. 6.9

and direction along the line joining the point charge q and point P, being away for the positive charge and towards for the negative charge.

Electric Field due to Many Point Charges

The electric field due to many point charges $q_j \equiv q_1, q_2, q_3,$ .... at a point P at the distances $r_j \equiv r_1, r_2, r_3, r_4,$ .... from the charges q_j is given by the superposition principle, i.e.,

$$\vec{E}=\vec{E}_1+\vec{E}_2+\vec{E}_3+\vec{E}_4+\ldots\ldots\ldots\ldots \equiv \sum_j \vec{E}_j$$

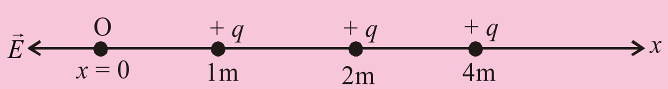
where $j = 1, 2, 3, 4,$ .... The magnitude E_j due to a single point charge q_j at the distance r_j is

$$E_j=\left(\frac{1}{4\pi\varepsilon_0 K}\right)\left(\frac{q_j}{r_j^2}\right)$$

For example, the electric field at the origin ($x = 0$) due to an infinite number of positive point charges, each of the magnitude q, situated at the points $x = 1m, 2m, 4m,$ ...... has the magnitude

$$E=\left(\frac{1}{4\pi\varepsilon_0 K}\right)\left(\frac{q}{1^2}+\frac{q}{2^2}+\frac{q}{4^2}+\frac{q}{8^2}+\ldots\ldots\right)$$

$$=\left(\frac{q}{4\pi\varepsilon_0 K}\right)\left(1+\frac{1}{4}+\frac{1}{16}+\frac{1}{64}+\ldots\ldots\ldots\ldots\right)=\left(\frac{q}{4\pi\varepsilon_0 K}\right)\left(\frac{1}{1-1/4}\right)=\frac{4}{3}\left(\frac{q}{4\pi\varepsilon_0 K}\right)$$



If the infinite number of point charges are alternately positive and negative, then the electric field has the magnitude

$$E=\left(\frac{1}{4\pi\varepsilon_0 K}\right)\left(\frac{q}{1^2}-\frac{q}{2^2}+\frac{q}{4^2}-\frac{q}{8^2}+\ldots\ldots\ldots\right)$$

$$=\left(\frac{q}{4\pi\varepsilon_0 K}\right)\left(1-\frac{1}{4}+\frac{1}{16}-\frac{1}{64}+\ldots\ldots\right)$$

$$=\left(\frac{q}{4\pi\varepsilon_0 K}\right)\left(\frac{1}{1+1/4}\right)=\frac{4}{5}\left(\frac{q}{4\pi\varepsilon_0 K}\right)$$

CHARGED CONDUCTOR CARRYING NO CURRENTS

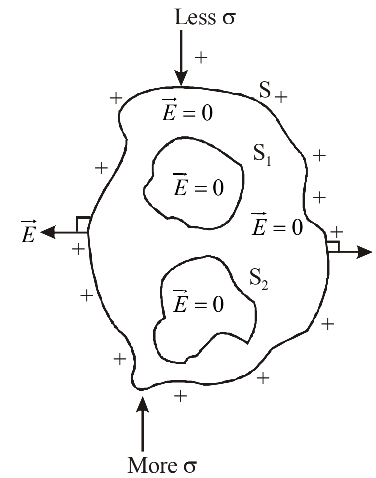


Fig. 6.10

Any charge given to a conductor spreads over the whole external-most surfaces S of the conductor, with the varying surface charge density σ. The surface charge density σ is more on the bulging parts and less on the flat parts of the external-most surface. No part of the charge given resides over the inner surfaces, S_1, S_2 .... etc. of the conductor, *i.e.,* the cavity surfaces, if any.

The electric field $\vec{E}$ is vanishing inside of the external-most surface S and, even, inside of the inner surfaces S_1, S_2,.... of the conductor. The field is nonvanishing on and near the surface S in the direction normal to it, being away from the conductor for the positive charge and towards for the negative charge.

Electric field, $E = \dfrac{\sigma}{\varepsilon_0 K}$

which shows that the field is independent of the position and depends on the surface charge density σ.

ELECTRIC LINES OF FORCE OR ELECTRIC FIELD LINES

The concept of electric field was introduced by Michael Faraday. The magnitude of electric field strength at any point is measured by the number of electric line of force passing per unit small area around that point normally and the direction of field at any point is given by the tangent to the line of force at the point.

An electric line of force is that imaginary smooth curve drawn in an electric field along which a free isolated unit positive charge moves.

Properties of Electric Lines of Force

(1) The lines of force diverge out from a +ve charge and converge at a – ve charge. More correctly the lines of force are always directed from higher to lower potential.

(2) The tangent drawn at any point on line of force gives the direction of force acting on a positive charge placed at that point.

(3) Two lines of force never intersect. If they are assumed to intersect, there will be two directions of electric field at the point of intersection, which is impossible.

(4) These lines have a tendency to contract in tension like a stretched elastic string. This actually explains attraction between opposite charges.

(5) These lines have a tendency to separate from each other in the direction perpendicular to their length. This explains repulsion between like charges.

(6) The no. of lines originating or terminating on a charge is proportional to the magnitude of charge. In rationalised MKS system $\left(\dfrac{1}{\varepsilon_0}\right)$ electric lines are associated with unit charge. So if a body encloses a charge q. Total line of force associated with it (called flux) will be $\dfrac{q}{\varepsilon_0}$.

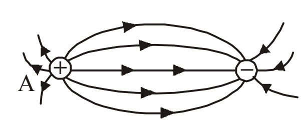


Fig. 6.11

(7) Total lines of force may be fractional as lines of force are imaginary.

(8) Line of force ends or starts normally on the surface of a conductor.

(9) If there is no electric field there will be no lines of force.

(10) Lines of force per unit area normal to the area at a point represents magnitude of intensity, electric lines represent strong field while distant weak field.

(11) Electric lines of force differ from magnetic lines of force.

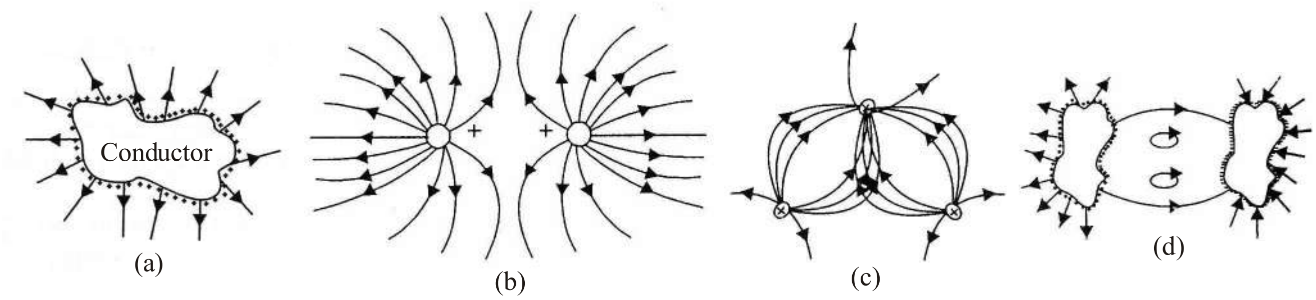
(a) Electric lines of force never form closed loop while magnetic lines are always closed or extended to infinity.

(b) Electric lines of force always emerge or terminate normally on the surface of charged conductor, while magnetic lines emanate from or terminate on the surface of a magnetic material at any angle.

(c) Electric lines of force do not exist inside a conductor but magnetic lines of force may exist inside magnetic material. Lines of force do not exist inside a conductor as field inside a conductor is zero.

CHECK Point

Which among the curves shown in figure cannot possibly represent electrostatic field lines?



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

Fig. 6.12

SOLUTION

(a) It is wrong, because electric field lines must be normal to the surface of conductor outside it.
(b) It is correct
(c) It is wrong, because electric field lines never intersect each other.
(d) It is wrong, because electric field lines cannot form closed loops.

ELECTRIC FLUX (ϕ)

The total number of electric lines of force through a given area is called the electric flux.

(i) For open surface, $\phi_0 = \int d\phi = \int \vec{E}\,.\,d\vec{s}$

(ii) For closed surface, $\phi_c = \oint \vec{E}\,.\,d\vec{s}$ (flux definition formula)

$\phi_c = \dfrac{q_{net}}{\varepsilon_0}$ or $4\pi k q_{net}$ (Gauss theorem formula).

$\phi = \vec{E}\,.\,d\vec{s} = Es\cos\theta$.

$\vec{s} \rightarrow$ always normal to surface and pointed outwards.

Electric flux is a scalar quantity

The **S.I. unit** of electric flux is $V-m$ or $N-m^2/C$

The value of electric flux 'ϕ' does not depend upon the distribution of charges and the distance between them inside the closed surface.

The **value of ϕ is zero in the following circumstances :**

(a) If a dipole is enclosed by a closed surface.
(b) Magnitude of +ve and –ve charges are equal inside a closed surface.
(c) If no charge is enclosed by a closed surface.
(d) In coming flux (–ve) = out going flux (+ ve).

(i) Electric field due to linear charge distribution, $E = \dfrac{\lambda}{2\pi\varepsilon_0 r}$ where λ = linear charge density

(ii) Electric field due to a plane sheet of charge $E = \dfrac{\sigma}{2\varepsilon_0}$ where, σ = surface charge density

(iii) Electric field near a charged conducting surface $E = \dfrac{\sigma}{\varepsilon_0}$

Electric field due to charged spherical shell or solid conducting sphere $E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{R^2}$

$E_{inside} = 0$, $E_{surface} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{R^2}$, $E_{outside}\ \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{R^2}$

ILLUSTRATION : 6.6

A surface encloses an electric quadrupole. What is the total electric flux through the surface?

SOLUTION :

An electric quadrupole consists of the two electric dipoles, each one having the two point charges $+q$, $-q$ and the zero net charge. Therefore, the net charge of a quadrupole is zero, and then, according to the Gauss's Law, the total electric flux through the surface enclosing the quadrupole given by the net charge inside of the surface divided by the permittinity ε_0, is zero.

ILLUSTRATION : 6.7

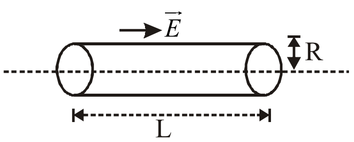


Fig. 6.13

A cylinder of radius R and length L is placed in a uniform electric field $\vec{E}$, parallel to its axis, as shown. Calculate the total electric flux through the surface of cylinder.

SOLUTION :

The cylinder is simply placed in the uniform electric field $\vec{E}$ which may otherwise be in any direction, and it does not have any charge enclosed inside of it. Therefore, according to the Gauss's law, the total electric flux through the surface of cylinder must be zero.

ELECTRIC POTENTIAL

It is the amount of work done by an external force in moving a unit positive charge (without acceleration) from one point to another in an electrostatic field. In case both the points are within the electrostatic field work done per unit positive charge is called potential difference.

When first point lies at infinity work done per unit positive charge is called potential at the second point.

$$V_B - V_A = \frac{W_{AB}}{q_0}$$

ELECTRIC POTENTIAL DIFFERENCE

Electric potential difference between two points A and B in an electric field is defined as *the amount of work done per unit charge to move a test charge q_0 from A to B, always keeping it in equilibrium, against the electrostatic force of the field along any path between the two points.*

$$V_B - V_A = \frac{W_{AB}}{q_0} = -\int_A^B \vec{E}.\vec{dl}$$

$$\text{or } \frac{W_{AB}}{q_0} = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r_B} - \frac{1}{r_A}\right] (\text{Unit} = \text{JC}^{-1})$$

where r_A are r_B are position vectors of points A and B respectively.

Electric Potential due to a Point Charge

Electric potential at a point in an electric field is the amount of work done in moving a unit positive test charge from infinity to taht point against the electrostatic forces, along any path.

$$V = \frac{q}{4\pi\varepsilon_0}\frac{q}{r}$$

where r is the position vector of the point, and q is the source charge.

Electric Potential due to a Group of Point Charges

Electric potential at a point due to a group of point charges is the algebraic sum of the potentials due to individual charge.

$$V = \frac{q}{4\pi\varepsilon_0 r^2}\sum_{i=1}^{n}\frac{q_i}{r_i}$$

Potential on Axial line of an Electric Dipole

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

Potential on Equatorial line of an Electric Dipole

$V = 0.$

as electric potential at a point due to an electric dipole is given by the relation

$$V = \frac{p\cos\theta}{4\pi\varepsilon_0 r^2}$$

where θ is the angle between the dipole moment vector and the position vector of the point from the centre of the dipole.

Relation between Electric Field and Potential Gradient

The potential gradient $\frac{dV}{dx}$ at a point (along the x-axis) and the electric field intensity E, at that point are related as:

$$E = -\frac{dV}{dx}$$

Here the negative sign indicates that although the electric field vector and potential gradient vector are along the same line, they are oppositely directed.

EQUIPOTENTIAL SURFACES

(a) An equipotential surface is a surface, every point of which is at the same electric potential.

(b) the electric potential gradient $\frac{dV}{dx}$ along an equipotential surface will be zero and hence the electric field along an equipotential surface will be zero. Thus, electric field will only be normal to an equipotential surface.

(c) No work is done in moving a charge between two points on an equipotential surface.

(d) As equipotential surfaces are normal to E, they also do not cross/intersect each other.

ELECTROSTATIC POTENTIAL ENERGY

The electrostatic potential energy of a point charge q placed at a point in the electric field $\vec{E}$ is given by

$$U = qV$$

i.e., it is the work done in displacing the point charge q from the reference point which is arbitrarily chosen at infinity and U is arbitraily taken zero there, to that point. The electrostatic potential energy gain $(U_B - U_A)$ in displacing the charge q from the point A to the point B in the electric field $\vec{E}$ is equal to the work done in displacing the charge q from A and B. Therefore,

$$(U_B - U_A) = q\,(V_B - V_A)$$

where $(V_B - V_A)$ is the electrostatic potential difference between the points A and B. This gain may be positive, or zero, or negative, depending on the charge and the electrostatic potential difference. For example, when an electron of charge $-e$ moves from a lower to higher potential, it loses its electrostatic potential energy. The loss, or gain, of electrostatic potential energy is normally expressed in the unit, i.e.,

$$1\,eV \equiv 1.6 \times 10^{-19}\,\text{J}$$

The electrostatic potential energy of a system of two point charge q_1 and q_2, separated by a distance r_{12}, is

$$U = \left(\frac{1}{4\pi\varepsilon_0 K}\right)\left(\frac{q_1 q_2}{r_{12}}\right)$$

which is defined as the amount of work done in assembling the two point charges from the infinite separation between them. The electrostatic potential energy of a system of three point charges q_1, q_2 and q_3, having the separation r_{12} between q_1, q_2, separation r_{23} between q_2, q_3 and separation r_{31} between q_3, q_1, becomes

$$U = \left(\frac{1}{4\pi\varepsilon_0 K}\right)\left(\frac{q_1 q_2}{r_{12}} + \frac{q_2 q_3}{r_{23}} + \frac{q_3 q_1}{r_{31}}\right)$$

which is equal to the amount of work done in assembling the system of three point charges from the infinite separations between them.

CHECK Point

A balloon may easily be charged to several thousand volts. Does that mean it has several thousand joules of energy? Explain.

SOLUTION

No, it doesn't mean that the balloon has several thousand joules of energy always. It can have several thousand joules of energy only if the balloon acquires high charge.

ILLUSTRATION : 6.8

Three point charges q_1, q_2 and q_3 of $0.1C$ each are placed at the corners of an equilateral triangle of the side 1m. If this system is supplied energy at the rate of 1kW, then how much time will be required to move one of the charges to the mid point of the line joining the others?

SOLUTION :

The three charges are at the corners of an equilateral triangle, as shown.

The total electrostatic potential energy of the system is

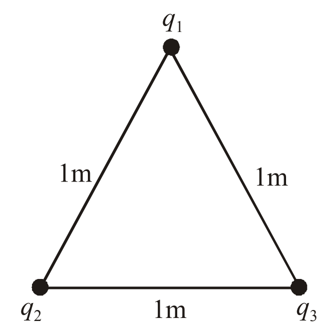


Fig. 6.14

$$U_1 = \left(\frac{1}{4\pi\varepsilon_o}\right)\left(\frac{q_1 q_2}{r_{12}} + \frac{q_2 q_3}{r_{23}} + \frac{q_3 q_1}{r_{31}}\right)$$

$$= (9\times 10^9)\left(\frac{0.1\times 0.1}{1} + \frac{0.1\times 0.1}{1} + \frac{0.1\times 0.1}{1}\right) = 2.7\times 10^8 \text{J}$$

When one of the charges, say q_1, is moved to the mid point of the line joining the other two charges, as shown,

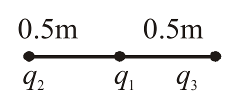


Fig. 6.15

The total electrostatic potential energy of the system will be

$$U_2 = (9\times 10^9)\left(\frac{0.1\times 0.1}{0.5} + \frac{0.1\times 0.1}{0.5} + \frac{0.1\times 0.1}{1}\right) = 4.5\times 10^8 \text{J}$$

Then, the total energy supplied to the system becomes

$$\Delta U = U_2 - U_1 = (4.5 - 2.7)\times 10^8 = 1.8\times 10^8 J$$

As the power supplied to the system is $1kW \cong 1000W$, we have the time taken in supplying the energy ΔU,

i.e., $t = \dfrac{1.8\times 10^8}{1000} = 1.8\times 10^5 s \cong 50h$

ILLUSTRATION : 6.9

Two identical point charges, $+q$ and $+q$ are placed on the x-axis at the points $x = a$ and $x = -a$, respectively. A third point charge Q is placed at the origin $x = 0$. Prove that the change in the lectrostatic potential energy of Q is approximately,

$$\Delta U = \left(\frac{1}{4\pi\varepsilon_0}\right)\left(\frac{2Qqd^2}{a^3}\right)$$ **when it is displaced by a distance $d << a$ along the x-axis.**

SOLUTION :

Before the displacement of the point charge Q, its electrostatic potential energy is

$$U_1 = \left(\frac{1}{4\pi\varepsilon_0}\right)\left(\frac{Qq}{a} + \frac{Qq}{a}\right) = \left(\frac{1}{4\pi\varepsilon_0}\right)\left(\frac{2Qq}{a}\right)$$

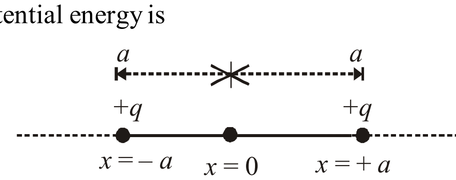


Fig. 6.16

When Q is displaced by a distance $d << a$ in the $+x$ direction, then its electrostatic potential energy becomes

$$U_2 = \left(\frac{1}{4\pi\varepsilon_0}\right)\left[\frac{Qq}{(a+d)} + \frac{Q}{(a-d)}\right] = \left(\frac{1}{4\pi\varepsilon_0}\right)\left[\frac{2aQq}{(a^2-d^2)}\right]$$

$$= \left(\frac{1}{4\pi\varepsilon_0}\right)\left(\frac{2Qq}{a}\right)\left(1-\frac{d^2}{a^2}\right)^{-1} \approx \left(\frac{1}{4\pi\varepsilon_0}\right)\left(\frac{2Qq}{a}\right)\left(1+\frac{d^2}{a^2}\right)$$

Now, the change, i.e., increase, in the electrostatic potential energy of Q becomes

$$\Delta U = U_2 - U_1 \approx \left(\frac{1}{4\pi\varepsilon_0}\right)\left(\frac{2Qq}{a}\right)\left(\frac{d^2}{a^2}\right) \approx \left(\frac{1}{4\pi\varepsilon_0}\right)\left(\frac{2Qqd^2}{a^3}\right)$$

Knowledge ENHANCER

The torque τ on a dipole in uniform electric field as shown in figure is given by, $\tau = qE \times 2\ell \sin\theta = \vec{p} \times \vec{E}$

So τ is maximum, when dipole is $\perp$ to field & minimum (=0) when dipole is parallel or antiparallel to field.

If $\vec{p} = p_x\hat{i} + p_y\hat{j} + p_z\hat{k}$ and $\vec{E} = E_x\hat{i} + E_y\hat{j} + E_z\hat{k}$

Then $\vec{\tau} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ p_x & p_y & p_z \\ E_x & E_y & E_z \end{vmatrix}$

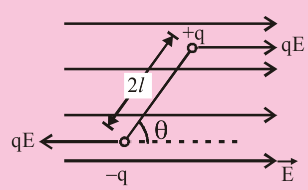


Fig.6.17

The work done in rotating the dipole from equilibrium through an angle $d\theta$ is given by

$dW = \tau d\theta = pE\sin\theta\, d\theta$

And from $\theta_1 \to \theta_2$, $W = \int_{\theta_1}^{\theta_2} dW = \int_{\theta_1}^{\theta_2} pE\sin\theta\, d\theta$

If $\theta_1 = 0$ i.e equilibrium position, then

$$W = \int_0^{\theta_2} pE\sin\theta d\theta = pE(1-\cos\theta_2)$$

Workdone in rotating an electric dipole in uniform electric field from θ_1 to θ_2 is $W = pE(\cos\theta_1 - \cos\theta_2)$

Time period of a dipole in uniform electric field is

$$T = 2\pi\sqrt{\frac{I}{pE}}$$

where I = moment of inertia of the dipole about the axis of rotation.

Potential energy of an electric dipole in an electric field is,

$$U = -\vec{p}.\vec{E} \quad \text{i.e. } U = -pE\cos\theta$$

where θ is the angle between $\vec{E}$ and $\vec{p}$.

We can also write

$$U = p_xE_x + p_yE_y + p_zE_z$$

Electric field due to an electric dipole

(a) Alogn axial line (end-on position)

$\vec{p}$ and $\vec{E}$ are parallel

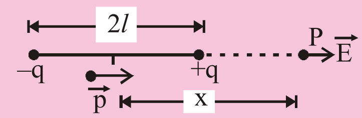


Fig. 6.18

$$E_{ax} = \frac{1}{4\pi\varepsilon_0}.\frac{2px}{(x^2-l^2)^2} \quad \text{when } x >> l$$

(b) Along equatorial line (Broad - side on position)

$$E_{eq} = \frac{1}{4\pi \in_0} \cdot \frac{p}{(x^2 + \ell^2)^{3/2}} \text{ where } x >> l$$

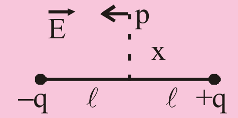


Fig. 6.19

$\vec{p}$ and $\vec{E}$ are anti parallel i.e when $x >> l$, $E_{ax} = 2E_{eq}$

(c) At any point (for first dipole)

$$E = \frac{1}{4\pi \in_0} \frac{p}{x^3} \sqrt{3\cos^2\theta + 1} \text{ ; } \tan\beta = \frac{1}{2}\tan\theta$$

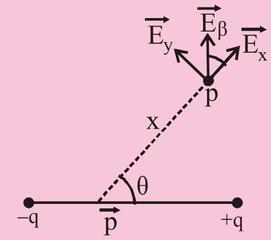


Fig.6.20

(d) Electric field intensity due to a point charge varies inversely as cube of the distance and in case of quadrupole it varies inversely as the fourth power of distance from the quadrupole.

ILLUSTRATION : 6.10

Calculate the electric field intensity due to a dipole of length 10 cm and having a charge of 500 μC at a point on the axis distant 20 cm from one of the charges in air.

SOLUTION :

The electric intensity on the axial line of the dipole is given by

$$E_{axial} = \frac{1}{4\pi\varepsilon_o} \times \frac{2rp}{\left[r^2 - \left(\frac{a}{2}\right)^2\right]^2}$$

Here, $a = 10$ cm or $a/2 = 5 \times 10^{-2}$ m, $r = (20 + 5)$ cm $= 25 \times 10^{-2}$ m

$p = q \times a = (500 \times 10^{-6}) \times (10 \times 10^{-2}) = 5 \times 10^{-5}$ Cm

$$E_{axial} = (9 \times 10^9) \times \frac{2 \times (25 \times 10^{-2}) \times (5 \times 10^{-5})}{10^{-8}[(25)^2 - (5)^2]^2} = 3.25 \times 10^7 \text{ NC}$$

CAPACITORS AND CAPACITANCE

A capacitor or condenser *is a device that stores electrical energy. It consists of conductors of any shape and size carrying charges of equal magnitude and opposite signs and separated by an insulating medium*

The symbol of a capacitor is —| |— or —| (—

The net charge on a capacitor is zero.

Capacitance or **capacity** *of a capacitor is a measure of ability of the capacitor to store charge on it.*

When a conductor is charged then its potential rises. The increase in potential is directly proportional to the charge given to the conductor.

i.e., $Q \propto V$ or $Q = CV$ or, $C = \frac{Q}{V}$

The constant C is known as the **capacitance of the conductor.**

Capacitance is a scalar quantity.

Its **SI unit** is farad (F) or coulomb/volt

$$1 \text{ farad} = \frac{\text{IC}}{\text{IV}} = \frac{3 \times 10^9 \text{ esu of charge}}{(1/300) \text{ esu of potential}} = 9 \times 10^{11} \text{ state farad (esu of capacity)}$$

Capacitance depends on :

(i) Area of the conductor : If the surface area of a conductor is increased keeping charge q constant its potential decreases and hence the capacity increases $C = \frac{q}{V}$

(ii) The presence of other conductor in the vicinity of the charged conductor: The presence of other conductor near a charged conductor decreases the potential of the charged conductor, there by the capacity increases.

(iii) The medium around the charged conductor : If the capacity of the conductor is C when air is the medium around it, then the capacity becomes KC when another medium of dielectric constant K is around it. This is because of the reason that potential becomes V/K.

Capacitance is independent of :

(i) Charge on conductor
(ii) Potential of conductor
(iii) Nature of material and theckness of the conductor.

Principle of a capacitor : Consider a conducting plate M which is given a charge Q such that its potential rises to V, then,

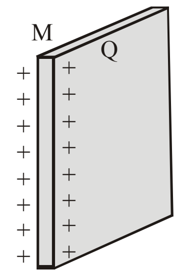


Fig. 6.21

Capacitance, $C = \frac{Q}{V}$

where C is the capacitance of the capacitor.
Let us now place another identical conducting plate N parallel to it such that charge is induced on plate N as shown in figure.
If V_- is the potential at M due to induced negative charge on N and V_+ is the potential at M due to induced positive charge on N, then

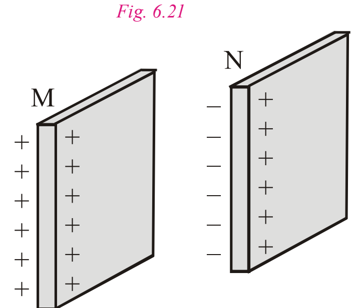


Fig. 6.22

$$C' = \frac{Q}{V'} = \frac{Q}{V + V_+ - V_-}$$

Since V' < V (as the induced negative charge lies closer to the plate M in comparison to induced positive charge).
Therefore, $C' > C$
Further, if N is earthed from the outer side (see figure) then
$V'' = V_+ - V_-$ (Since the entire positive charge flows to the earth)

Therefore, $C'' = \frac{Q}{V''} = \frac{Q}{V_+ - V_-}$ $\quad\therefore\ C'' >> C$

If an identical earthed conductor is placed in the vicinity of a charged conductor then the capacitance of the charged conductor increases appreciable. This is the principle of a parallel plate capacitor.

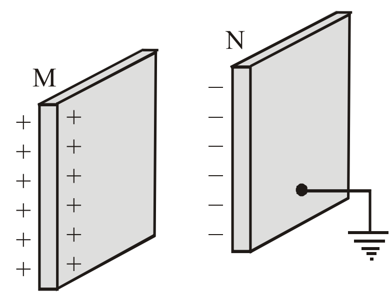


Fig. 6.23

DIFFERENT TYPES OF CAPACITOR

The Parallel Plate Capacitor

The capacitor has two parallel metallic plates of any shape each of surface area A. Both these plates are separated by a distance d apart. Plate 1 is given a positive charge so that equal negative charge is induced on the plate 2 which is earthed from outside. This earthing reduces the potential difference between the plates, as a result capacitor can store more charge and hence its capacity C increases.

The capacitance is given by, $C = \frac{K\varepsilon_0 A}{d}$

where K is the dielectric constant of the medium in between the plates.

Special cases :

(i) When medium between the plates is air ($K \simeq 1$)

$$C = \frac{\varepsilon_0 A}{d}$$

(ii) When the space between the capacitor is partly filled with the dielectric,

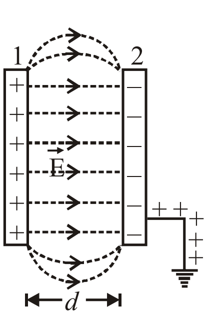


Fig. 6.24

$$C = \frac{\varepsilon_0 A}{d - t + \frac{t}{K}} = \frac{\varepsilon_0 A}{d - t\left(1 - \frac{1}{K}\right)}$$

where t is the thickness of dielectric medium between the plates. The induced charge on the dielectric faces is q′, which is given as

$$q' = -\left(1 - \frac{1}{K}\right) q$$

(iii) When a metallic sheet of thickness t (t < d) is introduced between the plates, then

$$C = \frac{\varepsilon_0 A}{d - t}$$

(iv) When the space between the plates is filled with a dielectric medium which linearly varies as such its value near one plate is K_1, and that near the other plate is K_2, then

$$C = \frac{\varepsilon_0 A(K_2 - K_1)}{\log_e(K_2 / K_1)}$$

(v) If the space between the plates of a parallel plate capacitor is filled with two dielectric medium of thicknesses d_1 and d_2 ($d = d_1 + d_2$) having dielectric constants K_1 and K_2 then

the capacitance will be, $C = \dfrac{\varepsilon_0 A}{\frac{d_1}{K_1} + \frac{d_2}{K_2}}$

Spherical Capacitor

A spherical capacitor consists of two concentric spherical conductors of radii R_1 and R_2.

Case I : When outer sphere is earthed :

When a charge Q is given to inner sphere it is uniformly distributed on its surface A charge –Q is induced on inner surface of outer sphere. The charge +Q is induced on outer surface of outer sphere flows to earth as it is grounded.

$E = 0$ for $r < R_1$

and $E = 0$ for $r > R_2$

Potential of inner sphere

$$V_1 = \frac{Q}{4\pi\varepsilon_0 R_1} + \frac{-Q}{4\pi\varepsilon_0 R_2}$$

$$\Rightarrow \frac{Q}{4\pi\varepsilon_0}\left(\frac{R_2 - R_1}{R_1 R_2}\right)$$

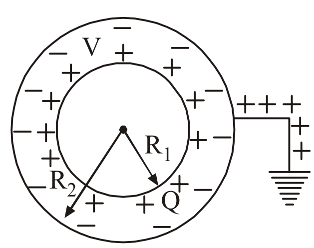


Fig. 6.25

As outer surface is earthed so potential

$V_2 = 0$

Potential difference between plates $V = V_1 - V_2 = \dfrac{Q}{4\pi\varepsilon_0}\left(\dfrac{R_2 - R_1}{R_1 R_2}\right)$

so, $C = \dfrac{Q}{V} = 4\pi\varepsilon_0 \dfrac{R_1 R_2}{R_2 - R_1}$ (*in air or vacuum*)

In presence of medium between plates

$$C = 4\pi\varepsilon_r \varepsilon_0 \frac{R_1 R_2}{R_2 - R_1}$$

Case II : When inner sphere is earthed

Here the system is equivalent to a spherical capacitor of inner and outer radii R_1 and R_2 respectively and a spherical conductor of radius R_2 in parallel.

This is because charge Q given to outer sphere distributes in such a way that for the outer sphere charge on the inner side is,

$\frac{R_1}{R_2}Q$ and charge on the outer side is

$$Q - \frac{R_1}{R_2}Q = \frac{(R_2 - R_1)}{R_2}Q$$

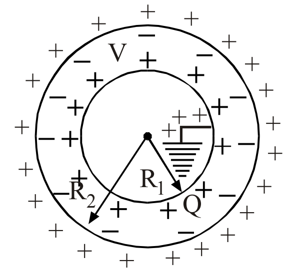


Fig. 6.26

So total capacity of the system, $C = 4\pi\varepsilon_0 \frac{R_1R_2}{R_2 - R_1} + 4\pi\varepsilon_0 R_2$ or, $C = \frac{4\pi\varepsilon_0 R_2^2}{R_2 - R_1}$

ILLUSTRATION : 6.11

If the distance between the plates of a parallel plate capacitor is made half and the area of plates is doubled then what will be the capacitance?

SOLUTION

As we know, capacitance, $C = \frac{\varepsilon_0 A}{d}$

$$\Rightarrow \frac{C_1}{C_2} = \frac{A_1}{A_2}\frac{d_2}{d_1} = \frac{A_1}{2A_1} \times \left(\frac{1}{d_1}\right)\left(\frac{d_1}{2}\right) = \frac{1}{4} \Rightarrow C_2 = 4C_1$$

ENERGY STORED IN A CAPACITOR

When a conductor is charged its potential changes from 0 to V and work is done against repulsion between charge stored on the conductor and charge coming from the charging body. This work is stored as electrostatic potential energy (U).

$$U = \frac{q^2}{2C} = \frac{1}{2}qV = \frac{1}{2}CV^2.$$

The energy is stored in the electric field between the plates of the capacitor.

- ***The energy stored per unit volume in the electric field between the plates is called energy density.***

Energy density, $u = \frac{1}{2}\varepsilon_0 E^2 = \frac{1}{2}\frac{\sigma^2}{\varepsilon_0}.$

WORK DONE BY BATTERY

Work done by battery is given by

W = Charge that flow through battery × battery EMF

Whenever there is a charging of capacitor, work done by battery, in part is stored as electrostatic energy in between capacitor plates and remaining is dissipated as heat due to charge flow through connecting wires.

In general, heat produced is given by *H = work done by battery – energy stored in capacitor*

CHECK Point

What meaning would you give to the capacitance of a single conductor?

SOLUTION

It means that a single conductor is a capacitor whose other plate can be considered to be at infinity.

COMBINATION OF CAPACITORS

Series Combination of Capacitors

In this arrangement of capacitors the charge has no alternative path(s) to flow.

Let us consider a number of capacitors, connected in series, as shown.

They have the same charge q but the different electric potential differences $V_1, V_2, V_3, \ldots\ldots\ldots\ldots, V_n$ across them due to their different capacitances $C_1, C_2, C_3, \ldots\ldots\ldots, C_n$. The total electric potential difference applied across the combination is

$$V = V_1 + V_2 + V_3 + \ldots\ldots\ldots\ldots\ldots$$

$$= \frac{q}{C_1} + \frac{q}{C_2} + \frac{q}{C_3} + \ldots\ldots\ldots\ldots$$

$$= q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots\ldots\ldots\ldots\right)$$

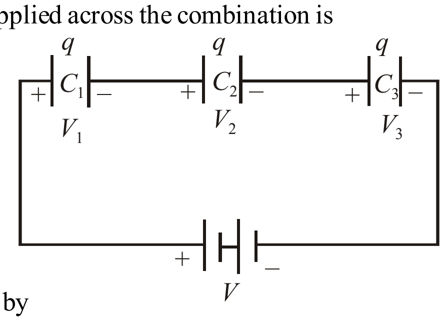


Fig. 6.27

Therefore, the equivalent capacitance C of the series combination is given by

$$\frac{1}{C} = \frac{V}{q} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots\ldots\ldots + \frac{1}{C_n}$$

Evidently, therefore, the equivalent capacitance C is smaller than each one of the capacitances of combination.

Parallel Combination of Capacitiors

In this arrangement of capacitors, the charge has an alternative path(s) to flow.

We, now, consider a number of capacitors, connected in parallel, as shown. They have the same electric potential difference V across them, but the different charges $q_1, q_2, q_3 \ldots\ldots\ldots, q_n$ on them due to their different capacitances $C_1, C_2, C_3 \ldots\ldots, C_n$.

The total charge of the combination is

$$q = q_1 + q_2 + q_3 + \ldots\ldots\ldots\ldots$$

$$= C_1 V + C_2 V + C_3 V + \ldots\ldots\ldots\ldots$$

$$= V(C_1 + C_2 + C_3 + \ldots\ldots\ldots\ldots)$$

from which we have the equivalent capacitance of the combination,

$$\text{i.e., } C = \frac{q}{V} = C_1 + C_2 + C_3 \ldots\ldots$$

Evidently, therefore, the equivalent capacitance C is more than each one of the capacitances of combination.

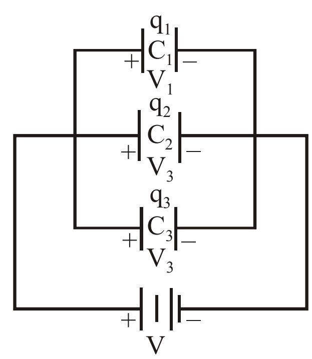


Fig. 6.28

ILLUSTRATION : 6.12

A circuit is shown in figure. Find the charge on the condenser having a capacity of 5 μF.

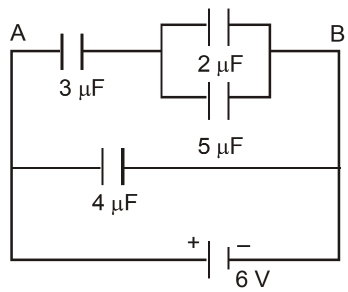


Fig. 6.29

SOLUTION :

Potential difference between A and B = 6 volts. The condensers of capacitance 2 μF and 5 μF are in parallel.

Their effective capacitance, C = 2 + 5 = 7 μF.

The capacitance between A and B is given by $C' = \frac{C \times 3}{C+3} = \frac{7 \times 3}{7+3} = \frac{21}{10}\,\mu F$

Total charge $Q = CV = \frac{21}{10} \times 6 = \frac{63}{5}\,\mu C$

Total potential difference across 3 μF capacitor, is $V_1 = \frac{Q}{3} = \frac{63}{5} \times \frac{1}{3} = \frac{21}{5}$ volts

Hence the common potential difference across the condensers in parallel is $V_2 = 6 - \frac{21}{5} = \frac{9}{5}$ V

So, the charge on 5 μF condenser is $Q = 5 \times V_2 = 5 \times \frac{9}{5} = 9\,\mu C$

ILLUSTRATION : 6.13

In the given circuit, consisting of the four capacitors and a battery, the potential difference across the 7 μF capacitors is 6V. Then, calculate the potential differences across the remaining three capacitors and the battery emf.

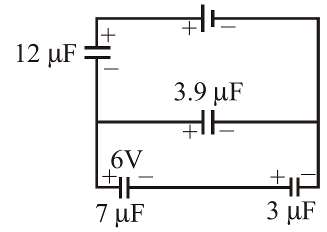


Fig. 6.30

SOLUTION :

The capacitors of $7\mu F$ and $3\mu F$ are in series and therefore, they have the same charge on them and the potential differences across them are in a ratio equal to the inverse ratio of capacitances. Therefore, the potential difference across the $3\mu F$ capacitor is

$$= \frac{6V \times 7\mu F}{3\mu F} = 14V$$

The potential difference across the parallel combination of $3.9\mu F$ capacitor with the series combination of $7\mu F$ and $3\mu F$ capacitor is, therefore, 20V. The total capacitance of this combination is

$$= 3.9 + \frac{7 \times 3}{7+3} = 6\mu F$$

which is in series with the capacitor of 12 μF and therefore, they have same charge and the potential differences are in a ratio equal to the inverse ratio of capacitances. The potential difference across the $12\mu F$ capacitor becomes

$$= \frac{20V \times 6\mu F}{12\mu F} = 10V$$

and then, the battery emf $E = 20 + 10 = 30$ V.

LOSS OF ENERGY ON JOINING TWO CHARGED CONDUCTORS OR CAPACITORS

When the two charged conductors, having the capacitances C_1 and C_2 and the potentials V_1 and V_2, respectively, are connected together by the conducting wires, the charge flows from the higher potential say, V_1 to the lower potential say, V_2 till, the potentials of the two conductors are equalised. Then, the common potential of the two conductors will be

$$V = \frac{(q_1 + q_2)}{C_1 + C_2} = \frac{(C_1V_1 + C_2V_2)}{(C_1 + C_2)}$$

The same thing, as outlined above, happens, when the two charged capacitors are connected, with the plates of the like polarities together, by the conducting wires. Before connecting together, the total energy of the charged conductors, or capacitors, is

$$U_1 = \frac{1}{2}\left(C_1V_1^2\right) + \frac{1}{2}\left(C_2V_2^2\right)$$

Fig. 6.31

After connecting together, the total energy of charged conductors, or capacitors, will be

$$U_2 = \frac{1}{2}(C_1 + C_2)V^2 = \frac{(C_1V_1 + C_2V_2)}{2(C_1 + C_2)}$$

Therefore, the loss of energy becomes $\Delta U = U_1 - U_2 = \frac{1}{2}\left(\frac{C_1C_2}{(C_1 + C_2)}\right)(V_1 - V_2)^2$

which is mainly as the heat and also as the light and sound due to the sparking taking place. This loss is zero, when

$$V_1 = V_2 \qquad \Rightarrow \frac{q_1}{C_1} = \frac{q_2}{C_2} \Rightarrow \frac{q_1}{q_2} = \frac{C_1}{C_2}$$

i.e., the charges of the two conductors, or capacitors, before joining together are in the ratio of their capacitances.
After connecting together, the charges on the two conductors, or capacitors, will also be in the ratio of their capacitances,

i.e., $\frac{q_1'}{q_2'} = \frac{C_1V}{C_2V} = \frac{C_1}{C_2}$

ILLUSTRATION : 6.14

A 4μF capacitor is charged by a 200V supply. It is then disconnected from the supply and then, connected to another uncharged 2μF capacitor. How much electrostatic potential energy of the first capacitor is lost in the form of heat and other radiation?

SOLUTION :

The electrostatic potential energy of the first capacitor of 4μF capacitance, lost in the form of heat and other radiation, when it is charged by a 200 V supply and connected to another unchanged capacitor of 2μF capacitances after disconnection from the supply, is

$$\Delta U = \frac{1}{2}\left(\frac{C_1C_2}{C_1 + C_2}\right)(V_1 \sim V_2)^2 = \frac{1}{2}\left(\frac{4\times10^{-6}\times2\times10^{-6}}{4\times10^{-6} + 2\times10^{-6}}\right)(200 - 0)^2 = 2.67\times10^{-2}\text{J}$$

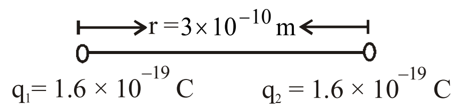
MISCELLANEOUS SOLVED EXAMPLES

1. Two protons in a molecule is separated by 3×10^{-10} m. Find the electrostatic force exerted by one proton on the other.

Sol. Here, $q_1 = q_2 = 1.6 \times 10^{-19} C$, $r = 3 \times 10^{-10} m$

According to Coulomb's law, the electrostatic force F between two charges q_1 and q_2, which are seperated by distance r is

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

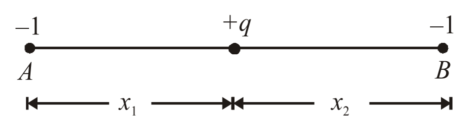


So, $F = 9 \times 10^9 \frac{(1.6 \times 10^{-19})^2}{9 \times 10^{-20}} = 2.56 \times 10^{-9} C$ (Repulsive)

2. Two negative charges of unit magnitude each and a positive charge q are placed along a straight line. At what position and for what value of q will the system be in equilibrium? Check whether it is stable, unstable or neutral equilibrium?

Sol. Let the charge $+q$ be held at a distance x_1 from unit negative charge at A, and at a distance x_2 from unit negative charge at B.

For equilibrium of q, $\frac{q(-1)}{4\pi\varepsilon_o x_1^2} = \frac{q(-1)}{4\pi\varepsilon_o x_2^2}$



$\therefore x_1 = x_2$ i.e. q must be equidistant from A and B.

For equilibrium of unit negative charge at B.

Force on B due to charge at A + force on B due to $q = 0$

$$\frac{(-1)(-1)}{4\pi\varepsilon_o (x_1 + x_2)^2} + \frac{q(-1)}{4\pi\varepsilon_o x_2^2} = 0 \quad \Rightarrow \quad \frac{1}{4\pi\varepsilon_o (2x_2)^2} = \frac{-(-q)}{4\pi\varepsilon_o x_2^2} \quad (\because x_1 = x_2)$$

$q = \frac{1}{4}$ i.e. $\frac{1}{4}$th of the magnitude of either unit charge.

Stability : If q is displaced slightly towards A, force of attraction due to A exceeds the force of attraction due to B. Therefore, q will get displaced further towards A. Hence the equilibrium of q is unstable.

However, if q is displaced in a direction $\perp$ to A, net force would bring q back to its normal position. Therefore, the equilibrium will be stable.

3. Electric force between two point charges q and Q at rest is F. Now if a charge $-q$ is placed next to q what will be the (a) force on Q due to q (b) total force on Q?

Sol. (a) As electric force between two body interaction, i.e., force between two particles, is independent of presence or absence of other particles, the force between Q and q will remain unchanged, i.e., F.

(b) An electric force is proportional to the magnitude of charges, total force on Q will be given by

$$\frac{F'}{F} = \frac{Qq'}{Qq} = \frac{q'}{q} = \frac{0}{q} = 0 \quad [\text{as } q' = q + (-q) = 0]$$

i.e., The resultant force on Q will be zero.

4. Calculate the electric field strength required to just support a water drop of mass 10^{-7} kg and having charge 1.6×10^{-19} C.

Sol. Here, $m = 10^{-7}$ kg, $q = 1.6 \times 10^{-19} C$

Step 1 : Let E be the electric field strength required to support the water drop.

Force acting on the water drop due to electric field E is $F = qE = 1.6 \times 10^{-19} E$

Weight of drop acting downward, $W = mg = 10^{-7} \times 9.8$ newton.

Step 2 : Drop will be supported if F and W are equal and opposite.

i.e., $1.6 \times 10^{-19} E = 9.8 \times 10^{-7}$

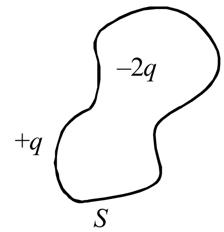
$$\therefore \quad E = \frac{9.8 \times 10^{-7}}{1.6 \times 10^{-19}} = 6.125 \times 10^{12} NC^{-1}.$$

5. ***n* small drops of same size are charged to *V* volt each. If they coalesc to form a single large drop, then what will be its potential?**

Sol. As Volume remains constant, therefore, $\frac{4}{3}\pi R^2 = n\times\frac{4}{3}\pi r^3$ $\therefore$ $R = n^{1/3}r.$

New potential $= V' = \frac{nq}{4\pi\varepsilon_0 R} = \frac{nq}{4\pi\varepsilon_0(n^{1/3}r)}$ $= n^{2/3}\frac{q}{4\pi\varepsilon_o r} = n^{2/3}V.$

6. **The following figure shows a surface *S* which is enclosing – 2*q* charge. The charge +*q* is kept outside the surface *S*. Calculate the net outward/ inward flux from the surface *S*.**

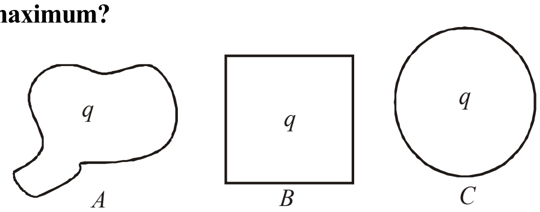


Sol. According to Gauss law, the net flux is

$\phi = \frac{1}{\varepsilon_0}\times$ net charge enclosed by closed surface $= \frac{-2q}{\varepsilon_0}$

Because $+q$ is outside the surface *S*, so net flux due to $+q$ thought *S* is zero.

7. **In which figure, the electric flux is maximum?**



Sol. According to Gauss law, the electric flux linked with a closed surface depends only on net charge enclosed by that surface. It does not depend on the shape and size of that closed surface. Hence electric flux linked in above three figures are same i.e., $\phi_A = \phi_B = \phi_C$.

8. **A charge *q* is enclosed in a cube. What is the electric flux associated with one of the faces of cube?**

Sol. According to Gauss theorem the total electric flux

$\phi = \frac{1}{\varepsilon_0}\times$ total enclosed charge $= \frac{1}{\varepsilon_0}\times q$.

Since cube has six faces, hence electric flux linked with each face $= (1/6\phi) = q/6\varepsilon_0$.

9. **A charge $Q\,\mu C$ is placed at the centre of a cube. What will be the flux coming out from any surface?**

Sol. According to Gauss's law

ϕ (flux from all six surfaces of cube) $= \frac{Q\,\mu C}{\varepsilon_0} = \frac{Q}{\varepsilon_o}\times 10^{-6}$

So, flux from any one of surface of cube $= \frac{Q}{6\varepsilon_o}\times 10^{-6}$

10. **A 10 mF capacitor is charged to a potential difference of 50 V and is connected to another uncharged capacitor in parallel. Now the common potential difference becomes 20 volt. What is the capacitance of second capacitor?**

Sol. Here, $q_1 = 10\times 50 = 500\ \mu C$, $C_1 = 10\mu F$, $C_2 = ?$, $q_2 = 0$

As $V = \frac{q_1+q_2}{C_1+C_2}$

$\therefore\ C_1 + C_2 = \frac{q_1+q_2}{V} = \frac{500+0}{20} = 25\,\mu F$

Therefore, $C_2 = 25 - C_1 = 25 - 10 = 15\,\mu F$

EXERCISE

DIRECTIONS (Qs. 1-42) : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. An electric dipole, consisting of two opposite charges of 2×10^{-6} C each separated by a distance 3 cm is placed in an electric field of 2×10^{5} N/C. Torque acting on the dipole is
(a) 12×10^{-1}N – m (b) 12×10^{-2}N – m
(c) 12×10^{-3}N – m (d) 12×10^{-4}N – m

2. If the potential of a capacitor having capacity 6 μF is increased from 10 V to 20 V, then increase in its energy will be
(a) 4×10^{-4} J (b) 4×10^{-6} J
(c) 9×10^{-4} J (d) 12×10^{-6} J

3. A charge q is placed at the centre of the line joining two exactly equal positive charges Q. The system of three charges will be in equilibrium, if q is equal to
(a) $-\frac{Q}{4}$ (b) $+Q$
(c) $-Q$ (d) $\frac{Q}{2}$

4. The formation of a dipole is due to two equal and unlike point charges placed at a
(a) short distance (b) long distance
(c) above each other (d) none of these

5. A parallel plate condenser with oil between the plates (dielectric constant of oil K = 2) has a capacitance C. If the oil is removed, then capacitance of the capacitor becomes
(a) $\sqrt{2}\,C$ (b) $2C$ (c) $\frac{C}{\sqrt{2}}$ (d) $\frac{C}{2}$

6. When air is replaced by a dielectric medium of force constant K, the maximum force of attraction between two charges, separated by a distance
(a) decreases K-times (b) increases K-times
(c) remains unchanged (d) becomes $\frac{1}{K^2}$ times

7. A capacitor is charged to store an energy U. The charging battery is disconnected. An identical capacitor is now connected to the first capacitor in parallel. The energy in each of the capacitors is
(a) $U/2$ (b) $3U/2$
(c) U (d) $U/4$

8. A charge Q is placed at the corner of a cube. The electric flux through all the six faces of the cube is
(a) $Q/3\varepsilon_0$ (b) $Q/6\varepsilon_0$
(c) $Q/8\varepsilon_0$ (d) Q/ε_0

9. In a parallel plate capacitor, the distance between the plates is d and potential difference across the plates is V. Energy stored per unit volume between the plates of capacitor is
(a) $\frac{Q^2}{2V^2}$ (b) $\frac{1}{2}\varepsilon_0\frac{V^2}{d^2}$
(c) $\frac{1}{2}\frac{V^2}{\varepsilon_0 d^2}$ (d) $\frac{1}{2}\varepsilon_0\frac{V^2}{d}$

10. Energy stored in a capacitor is
(a) $\frac{1}{2}QV$ (b) QV
(c) $\frac{1}{QV}$ (d) $\frac{2}{QV}$

11. Three capacitors each of capacity $4\mu F$ are to be connected in such a way that the effective capacitance is 6 μF. This can be done by
(a) connecting two in parallel and one in series
(b) connecting all of them in series
(c) connecting them in parallel
(d) connecting two in series and one in parallel

12. When a body is charged by induction, then the body
(a) becomes neutral
(b) does not lose any charge
(c) loses whole of the charge on it
(d) loses part of the charge on it

13. If a body is positively charged, then it has
(a) excess of electrons (b) excess of protons
(c) deficiency of electrons (d) deficiency of neutrons

14. On charging by conduction, mass of a body may
(a) increase (b) decreases
(c) increase or decrease (d) none

15. Coulomb's law is true for
(a) atomic distances (= 10^{-11} m)
(b) nuclear distances (= 10^{-15} m)
(c) charged as well as uncharged particles
(d) all the distances

16. Two charges are placed a certain distance apart. A metallic sheet is placed between them. What will happen to the force between the charges?
(a) increase (b) decrease
(c) remains unchanged (d) either 'a' or 'b'

17. Which of the following is best insulator?
(a) Carbon (b) Paper
(c) Graphite (d) Ebonite

18. Two spheres A and B of exactly same mass are given equal positive and negative charges respectively. Their masses after charging
(a) remains unaffected (b) mass of A > mass of B
(c) mass of A < mass of B (d) nothing can be said

19. What happens when some charge is placed on a soap bubble?
(a) its radius decreases (b) its radius increases
(c) the bubble collapses (d) none of the above

20. Quantisation of charge implies
(a) charge cannot be destroyed
(b) charge exists on particles
(c) there is a minimum permissible charge on a particle
(d) charge, which is a fraction of a coulomb is not possible.

21. Two charges are placed a certain distance apart in air. If a glass slab is introduced between them, the force between them will
(a) increase (b) decrease
(c) remains the same (d) be zero

22. A charge q_1 exerts some force on a second charge q_2. If third charge q_3 is brought near, the force of q_1 exerted on q_2
(a) decreases
(b) increases
(c) remains unchanged
(d) increases if q_3 is of same sign as q_1 and decreases if q_3 is of opposite sign.

23. A positively charged rod is brought near an uncharged conductor. If the rod is then suddenly withdrawn, the charge left on the conductor will be
(a) positive (b) negative
(c) zero (d) not sure

24. The ratio of electric force between two electrons to two protons separated by the same distance in air is
(a) 10^0 (b) 10^6
(c) 10^4 (d) none

25. The dielectric constant of a metal is
(a) ∞ (b) 0
(c) 1 (d) none

26. A metallic particle having no net charge is placed near a finite metal plate carrying a positive charge. The electric force on the particle will be
(a) towards the plate (b) away from the plate
(c) parallel to the plate (d) zero

27. If a body is charged by rubbing it, its weight
(a) remains precisely constant
(b) increases slightly
(c) decreases slightly
(d) may increase slightly or may decrease slightly

28. An electric field can deflect
(a) neutrons (b) X-rays
(c) γ-rays (d) α-particles

29. A hollow sphere of charge does not have electric field at
(a) outer point (b) interior point
(c) beyond 2 m (d) beyond 100 m

30. If one penetrates a uniformly charged solid sphere, the electric field E
(a) increases
(b) decreases
(c) is zero at all points
(d) remains same as at the surface

31. If one penetrates a uniformly charged spherical cloud, electric field strength
(a) decreases directly as the distance from the centre
(b) increases directly as the distance from the centre
(c) remains constant
(d) none of the above

32. Electric lines of force about a negative point charge are
(a) circular anticlockwise (b) circular clockwise
(c) radial, inwards (d) radial, outwards

33. Electric lines of force
(a) exist everywhere
(b) exist only in the immediate vicinity of electric charges
(c) exist only when both positive and negative charges are near one another
(d) are imaginary

34. Debye is the unit of
(a) electric flux (b) electric dipole moment
(c) electric potential (d) electric field intensity

35. An electric dipole will experience a net force when it is placed in
(a) a uniform electric field
(b) a non-uniform electric field
(c) both the above cases
(d) none of these

36. An electric dipole is kept in a uniform electric field. it experiences
(a) a force and a torque
(b) a force, but no torque
(c) A torque but no force
(d) neither a force nor a torque

37. A charge q is enclosed in a cube. What is the electric flux associated with one of the faces of cube
(a) q/ε_o (b) ε_o/q
(c) $6q/\varepsilon_o$ (d) $q/6\varepsilon_o$

38. A charge Q is placed at the corner of a cube. The electric flux through all the faces of the cube is
(a) Q/ε_o (b) $Q/6\varepsilon_o$
(c) $Q/8\varepsilon_o$ (d) $Q/3\varepsilon_o$

39. Positive electric flux indicates that electric lines of force are directed
(a) outwards (b) inwards
(c) outwards or inwards (d) none of these

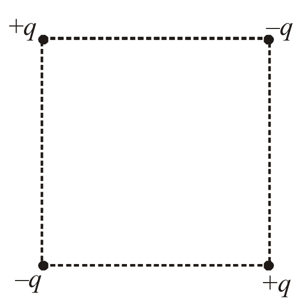
40. Electric flux at a point in an electric field is
(a) positive (b) negative
(c) zero (d) none of these

41. Electric flux over a surface in an electric field may be
(a) positive (b) negative
(c) zero (d) positive, negative, zero

42. The electric potential at a point on the equatorial line of an electric dipole is
(a) directly proportional to distance
(b) inversely proportional to distance
(c) inversely proportional to square of the distance
(d) none of the above

DIRECTIONS (Qs. 43-58): *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

43. Four electric charges are arranged as shown in the figure at the four corners of a square of side a. The potential energy of the system is:



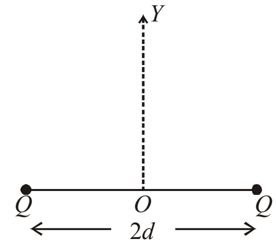
(a) zero (b) negative
(c) positive (d) greater than $\frac{1}{4\pi\varepsilon_0}\frac{2q^2}{a}$

44. Three charged particles are in equilibrium under their electrostatic forces only:
(a) the particles must be collinear
(b) all the charges cannot have the same magnitude
(c) all the charges cannot have the same sign
(d) the equilibrium is unstable

45. Inside a uniformly charged spherical conductor, the electric:
(a) potential is zero everywhere
(b) potential is non-zero and same everywhere
(c) field is zero everywhere
(d) field has the same magnitude everywhere but it is not zero

46. Four charges, all of the same magnitude are placed at the four corners of a square. At centre of the square, the potential is V and the field is E. By suitable choices of the signs of four charges, which of the following can be obtained?
(a) $V = 0, E = 0$ (b) $V = 0, E \neq 0$
(c) $V \neq 0, E = 0$ (d) $V \neq 0, E \neq 0$

47. Consider two identical charges placed at a distance 2d apart as shown in the figure. The equilibrium of a positive test charge placed at the point O midway between them may be:



(a) neutral
(b) stable for displacement along the x-axis
(c) stable for displacement along the y-axis
(d) unstable for displacement along the x-axis

48. Across the surface of a charged conductor, the electric:
(a) field is continuous (b) potential is continuous
(c) field is discontinuous (d) potential is discontinuous

49. A point charge is brought in an electric field. The electric field at a nearby point:
(a) will increase if the charge is positive
(b) will decrease if the charge is negative
(c) may increase if the charge is positive
(d) may decrease if the charge is negative

50. Which of the following quantities do not depend on the choice of zero potential or zero potential energy?
(a) Potential at a point
(b) Potential difference between the points
(c) Potential energy of a two charge system
(d) Change in potential energy of a two charge system

51. An electric dipole is placed at the centre of a sphere. Mark the correct option:
(a) the flux of the electric field through the sphere is zero
(b) the electric field is zero at every point of the sphere
(c) the electric field is not zero anywhere on the sphere
(d) the electric field is zero on a circle on the sphere

52. In a uniform electric field, equipotential surfaces must:
(a) be plane surfaces
(b) be normal to the direction of the field
(c) be placed such that surfaces having equal differences in potential are separated by equal distances
(d) have decreasing potentials in the direction of the field

53. S_1 and S_2 are two equipotential surfaces on which the potentials are not equal:
(a) S_1 and S_2 both cannot intersect
(b) S_1 and S_2 both cannot be plane surfaces
(c) in the region between S_1 and S_2, the field is maximum where they are closest to each other
(d) a line of force from S_1 to S_2 must be perpendicular to both

54. Which of the following is/are proportional to the inverse square of the distance x?
(a) The potential at a distance x from an isolated point charge
(b) The electric field at a distance x from an isolated point charge

(c) The force per unit length between two thin, straight, infinitely long current carrying conductors, parallel to each other, separated by a distance x
(d) The gravitational attraction between two small bodies kept at a distance x apart

55. A parallel plate capacitor is charged to a definite potential and the charging battery is disconnected. Now if the plates of capacitor are moved apart, then:
(a) the stored energy of the capacitor increases
(b) charge on the capacitor increases
(c) voltage of the capacitor increases
(d) the capacitance increases

56. A capacitor of capacity 100 μF is discharged through a resistance of 1000 ohm:
(a) its time constant is 1×10^{-1} s
(b) during time 0.693×10^{-1} s, the charge left on the capacitor is half of its maximum charge
(c) during its time constant charge left on the capacitor is 0.63 times to its maximum charge
(d) during its time constant, charge left on the capacitor is 0.37 times to its maximum charge

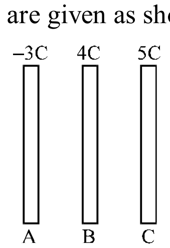
57. Two parallel plate capacitors are constructed one by a pair of iron plates and the second by a pair of copper plates of same area and same spacings. Then:
(a) the copper plate capacitor has a greater capacitance than the iron one
(b) both capacitors have equal, non-zero capacitances in the uncharged state
(c) both capacitors will have equal capacitances only if they are charged equally
(d) the capacitances of the two capacitors are equal even if they are unequally charged

58. Mark the correct statements?
(a) A given conducting sphere can be charged to any extent.
(b) A given conducting sphere cannot be charged to a potential greater than a certain value.
(c) A given conducting sphere cannot be charged to a potential less than a certain minimum value.
(d) None of the above

DIRECTIONS (Qs. 59-66): *Study the given paragraph(s) and answer the following questions.*

Passage – I

Three large plates A, B and C are placed parallel to each other and charges are given as shown.



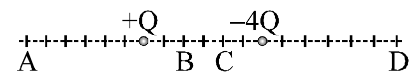
59. The charge that appears on the left surface of plate B is:
(a) 5C (b) 6C
(c) 3C (d) –3C

60. The charge on inner surface of plate C, if plate B is earthed,
(a) 5C (b) 6C
(c) 3C (d) –3C

61. The charge on left surface of B, if B and C both are earthed,
(a) 5C (b) 6C
(c) 3C (d) –3C

Passage – II

Related to the following diagram of two charges, +Q and – 4Q.



62. The net electric field is zero near which point?
(a) A (b) B
(c) C (d) D

63. At which point does the net electric field vector point to the left?
(a) A (b) B
(c) C (d) D

64. At which point would a small positive charge q feel the greatest force?
(a) A (b) B
(c) C (d) D

Passage – III

Two fixed charges –2 Q and Q are located at the points with coordinates (–3 a, 0) and (+ 3 a, 0) respectively in the X–Y plane.

65. All the points in the X–Y plane where the electric potential due to the two charges is zero, lie on a;
(a) straight line (b) circle
(c) parabola (d) ellipse

66. The expression for the potential $V(x)$ at a general point on the x-axis is given by:

(a) $V(x) = \frac{1}{4\pi\varepsilon_0}\left[\frac{Q}{3a-x} - \frac{2Q}{(3a+x)}\right]$ for $0 < x < 3a$

(b) $V(x) = \frac{1}{4\pi\varepsilon_0}\left[\frac{2Q}{3a-x} - \frac{Q}{(3a+x)}\right]$ for $0 < x < 3a$

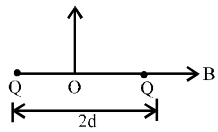
(c) $V(x) = \frac{1}{4\pi\varepsilon_0}\left[\frac{Q}{3a+x} - \frac{2Q}{(3a-x)}\right]$ for $0 < x < 3a$

(d) $V(x) = \frac{1}{4\pi\varepsilon_0}\left[\frac{Q}{3a-x} + \frac{2Q}{(3a+x)}\right]$ for $0 < x < 3a$

DIRECTIONS (Qs. 67-73): *Each of these questions contains an Assertion followed by Reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.
(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.
(c) If **Assertion** is **correct** but **Reason** is **incorrect**.
(d) If **Assertion** is **incorrect** but **Reason** is **correct**.

67. **Assertion :** Consider two identical charges placed distance 2d apart, along x-axis.



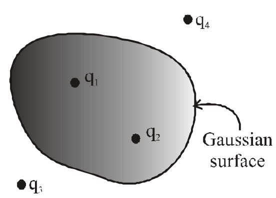
The equilibrium of a positive test charge placed at the point O midway between them is stable for displacements along the x-axis.

Reason: Force on test charge is zero.

68. **Assertion :** A deuteron and an α-particle are placed in an electric field. If F_1 and F_2 be the forces acting on them and a_1 and a_2 be their accelerations respectively then, $a_1 = a_2$.

Reason : Forces will be same in electric field.

69. **Assertion :** Four point charges q_1, q_2, q_3 and q_4 are as shown in figure. The flux over the shown Gaussian surface depends only on charges q_1 and q_2.

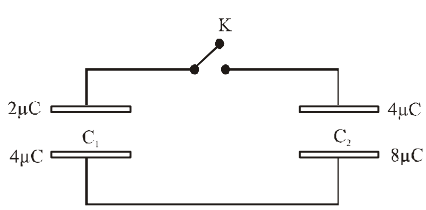


Reason : Electric field at all points on Gaussian surface depends only on charges q_1 and q_2.

70. **Assertion :** The positive charge particle is placed in front of a spherical uncharged conductor. The number of lines of forces terminating on the sphere will be more than those emerging from it.

Reason : The surface charge density at a point on the sphere nearest to the point charge will be negative and maximum in magnitude compared to other points on the sphere.

71. **Assertion :** Charges are given to plates of two plane parallel plate capacitors C_1 and C_2 (such that $C_2 = 2C_1$) as shown in figure. Then the key K is pressed to complete the circuit. Finally the net charge on upper plate and net charge on lower plate of capacitor C_1 is positive.



Reason : In a parallel plate capacitor both plates always carry equal and opposite charge.

72. **Assertion :** Each of the plates of a parallel-plate capacitor is given equal positive charge Q. The charges on the facing surfaces will be same.

Reason : A negative charge (–Q) will be induced on each of the facing surfaces.

73. **Assertion :** Electric potential and electric potential energy are different quantities.

Reason : For a system of positive test charge and point charge electric potential energy = electric potential.

DIRECTIONS (Qs. 74-77) : *Each question has four statements (A, B, C and D) given in Column I and five statements (p, q, r, s and t) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

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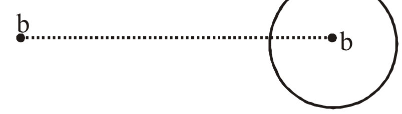
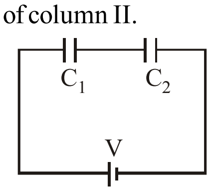
74. For the situation shown in the figure below, match the entries of column I with the entries of column II.



Column I	**Column II**
(A) If we displace the inside charge	(p) distribution of charge on the inner surface of conductor is uniform
(B) If we displace the outside charge	(q) distribution of charge on the inner surface of conductor is nonuniform
(C) In ths situation shown	(r) distribution of charge on the outer surface of conductor is uniform
(D) If outside charge is not present	(s) distribution of charge on the outer surface of conductor is nonuniform

	A	B	C	D
(a)	r, s	p	r, s	q
(b)	q, s	p, s	p, s	p, r
(c)	q, r	s	r	q
(d)	r, s	p, q	s	q, r

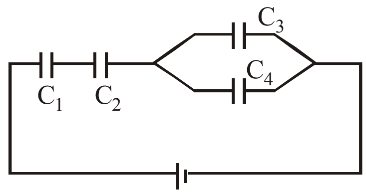
75. In the circuit shown in figure, plates of capacitor C_1 are gradually pulled apart. Then, match the entries of column I with the entries of column II.



Column I	**Column II**
(A) Potential difference across C_2	(p) will increase
(B) Charge on C_2	(q) will decrease
(C) Potential energy stored in C_2	(r) will remain same
(D) Electric field between plates of C_1	

	A	B	C	D
(a)	r	p	q	q
(b)	q	q	q	q
(c)	q	s	r	q
(d)	q	q	q	q

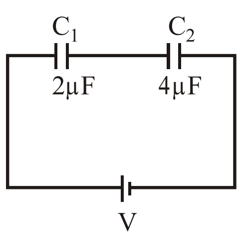
76. In the circuit shown in the following figure, $C_1 = C$, $C_2 = 2C$, $C_3 = 3C$, $C_4 = 4C$. Match the entries of column I with the entries of column II.



Column I	Column II
(A) Maximum potential difference	(p) across C_1
(B) Minimum potential difference	(q) across C_2
(C) Maximum potential energy	(r) across C_3
(D) Minimum potential energy	(s) across C_4

	A	B	C	D
(a)	p	r, s	p	r
(b)	r, s	r	p	r, s
(c)	p	r, s	q, r	s
(d)	s	q	r	p, r

77. In the given figure, the separation between the plates of C_1 is slowly increased to double of its initial value, then match the following.



Column I	Column II
(A) The potential difference across C_1	(p) increases
(B) The potential difference across C_2	(q) decreases
(C) The energy stored in C_1	(r) increases by a factor of 6/5
(D) The energy stored in C_2	(s) decreases by a factor of 18/25

	A	B	C	D
(a)	q, s	p, r	q, r	p
(b)	r, s	r	p, s	q
(c)	q	s	r	q
(d)	p, r	q	q, s	q

DIRECTIONS (Qs. 78-86): *Following are integer based/ Numeric based questions. Each question, when worked out will result in one integer or numeric value.*

78. Find the electric field between two metal plates 3 mm apart, connected to a 12 V battery.

79. Calculate the electric potential at the surface of a gold nucleus. Given, the radius of the nucleus = 6.6×10^{-15} m and atomic number of gold = 79.

80. Calculate the potential at a point P due to a charge of 4×10^{-7} C located 10 cm away.

81. At a point due to a point charge, the values of electric field intensity and potential are 32 N/C and 16 J/C respectively. Calculate magnitude of charges and distance of charge from the point of observation.

82. A parallel plate capacitor with air has a capacitance of 10 μF. If the distance between the plates is reduced to half and the space between them is filled with a material of dielectric constant 10, find the new capacitance.

83. Each plate of a parallel plate capacitor has an area of 6×10^{-3} m^2 and the distance between the plates is 3mm. Calculate the capacitance of the capacitor with air as dielectric. If this capacitor is connected to a 200 V supply, what is the change on each plate of the capacitor?

84. How much energy will be stored by a capacitor of 470 μF when charged by a battery of 20 V?

85. A given charge situated at a distance from an electric dipole in the end on position, experiences a force *F*. If the distance of charge is doubled, what will the force acting on the charge?

86. In a parallel plate capacitor the potential difference of 10^2 V is maintained between the plates. What will be the electric field at points A and B?

SOLUTIONS

Brief Explanations of Selected Questions

EXERCISE

1. (c) Charges (q) = 2×10^{-6} C, Distance (d)= 3 cm = 3×10^{-2} m and electric field (E) = 2×10^5 N/C. Torque (τ) = q.d.
E =$(2 \times 10^{-6}) \times (3 \times 10^{-2}) \times (2 \times 10^5)$
= 12×10^{-3} N–m .

2. (c) Capacitance of capacitor (C) = 6 μF = 6×10^{-6} F; Initial potential (V_1) = 10 V and final potential (V_2) = 20 V. The increase in energy (ΔU)

$$= \frac{1}{2}C\left(V_2^2 - V_1^2\right)$$

$$= \frac{1}{2} \times (6 \times 10^{-6}) \times [(20)^2 - (10)^2]$$

$$= (3 \times 10^{-6}) \times 300 = 9 \times 10^{-4} \text{ J}.$$

3. (a) At equilibrium, net force is zero

$$\therefore \frac{1}{4\pi\varepsilon_0} \times \frac{Qq}{(r/2)^2} + \frac{1}{4\pi\varepsilon_0} \times \frac{Q^2}{r^2} = 0$$

or $4q = -Q$ or $q = -\frac{Q}{4}$.

4. (a) Dipole is formed when two equal and unlike charges are placed at a short distance.

5. (d) When oil is placed between space of plates

$$C = \frac{2A\varepsilon_0}{d} \quad ...(1) \quad \left[\because C = \frac{KA\varepsilon_0}{d}, \text{ if } K = 2\right]$$

When oil is removed $C' = \frac{A\varepsilon_0}{d}$ ...(2)

On comparing both equations, we get C' = C/2

6. (a) In air, $F_{air} = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r^2}$

In medium, $F_m = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{Kr^2}$

$$\therefore \frac{F_m}{F_{air}} = \frac{1}{K} \Rightarrow F_m = \frac{F_{air}}{K} \text{ (decreases K-times)}$$

7. (a) In 1st case when capacitor C attached with battery charged with the energy.
U_1= U (stored energy on capacitor).
In IInd case after disconnect of battery similar capacitor is attached in parallel with Ist capacitor then C_{eq}.=C' = 2C.

$$\text{Now, } \frac{U_1}{U_2} = \frac{\frac{1}{2}\frac{q^2}{C}}{\frac{1}{2}\frac{q^2}{C'}} = \frac{C'}{C} = \frac{2C}{C} \qquad (\because C' = 2C)$$

$$U_2 = \frac{U}{2}$$

8. (d) According to Gauss's theorem,

electric flux through a closed surface $= \frac{q}{\varepsilon_0}$

where q is charge enclosed by the surface.

9. (b) Energy stored per unit volume

$$= \frac{1}{2}\varepsilon_0 E^2 = \frac{1}{2}\varepsilon_0 \left(\frac{V}{d}\right)^2 = \frac{1}{2}\varepsilon_0 \frac{V^2}{d^2} \quad \left(\because E = \frac{V}{d}\right)$$

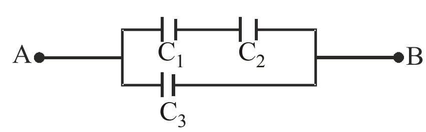
10. (a) Energy stored in capacitor

$$= \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q}{V}.V^2 \quad (Q = CV)$$

$$= \frac{1}{2}QV$$

11. (d) For series, $C' = \frac{C_1 \times C_2}{C_1 + C_2} = \frac{4 \times 4}{4 + 4} = 2\mu F$

For parallel, $C_{eq} = C' + C_3 = 2 + 4 = 6\mu F$



12. (b) Charging by induction involves transfer of charges from one part to the other of the body. No loss of charge is involved.

13. (c) Positive charge is due to deficiency of electrons.

14. (c) On charging by conduction, body may gain mass, if it acquires negative charge. It may lose mass, if it acquires positive charge.

15. (d) Coulomb's law is true for all distances small and large. Hence it is called a long range force.

16. (b) $F_m = \frac{F_0}{K}$. For metals $K = \infty$, therefore, $F_m \to 0$, in the thickness of sheet. Hence force between the charges will decrease.

17. (d) Ebonite is the best insulator.
18. (c) A loses electrons and B gains electrons. Therefore, mass of A < mass of B.
19. (b) The radius of soap bubble increases because of outward force acting on the bubble due to charging.
20. (d) $q = \pm ne$ shows that minimum value of $q = \pm 1e$. where $e = 1.6\times10^{-19}$ Coulomb = Charge of one electron
21. (b) $F_g = \frac{1 q_1 q_2}{4\pi\epsilon_0 r^2} = \frac{F_v}{K}$

As K (for glass) > 1. $\therefore\ F_g < F_v$
22. (c) The force of q_1 or q_2 is not affected by q_3. However, resultant force on q_2 will be affected.
23. (c) Positively charged rod induces negative charge on the side of the sphere closer to the rod and an equal positive charge on the side away from the rod.When the rod is withdrawn, the negative charges move to neutralise the equal positive charge. The charge left is zero.
24. (a) $\frac{F_{e.e}}{F_{p.p}} = 10^0 = 1$, because force depends only on charges, distance and nature of medium.
25. (a) Metal is a good conductor. So, its K = ∞.
26. (d)
27. (d) The weight can be increased slightly, if it acquire negative charge & weight can be decreased slightly, if it acquires positive charge.
28. (d) An electric field can deflect only a charged particle.
29. (b) E = 0, at any point inside the sphere.
30. (b) E decreases as we move from the surface of the sphere to its centre.
31. (a) A spherical cloud behaves as a solid sphere. Therefore, E decreases directly with the decreasing distance from the centre.
32. (c) For a single negative point charge, electric lines of force are radial and inwards.
33. (d) Electric lines of force are imaginary.
34. (b) Debye is the unit of electric dipole moment.
35. (b) Net force (as well as torque) are experienced by the dipole in a non uniform electric field.
36. (c) In a uniform electric field, net force = 0, but torque $\neq 0$.
37. (d) According to Gauss theorem-the total electric flux

$\phi = \frac{1}{\varepsilon_o} \times$ total enclosed charge $= \frac{1}{\varepsilon_o} \times q$.

Since cube has six faces. Hence electric flux linked with each face $= (1/6\phi) = q/6\varepsilon_o$.
38. (c) We require eight cubes to surround completely this corner charge. So, the flux through one cube is

$$\frac{1}{8}\times\frac{Q}{\varepsilon_o} = \frac{Q}{8\varepsilon_o}$$

39. (a) Positive electric flux is due to + charge. So lines of force are directed outwards.
40. (c) As area of a point is zero,

$\therefore\ \phi = E\,(ds)\cos\theta = E\cos\theta \times 0 = \text{Zero}.$
41. (d) Though electric flux is scalar, yet its value may be positive, negative or zero.
42. (d) At a point on equatorial line of electric dipole, V=0.
43. (b, c)
44. (a, b, c, d)
45. (b, c)
46. (a, b, c, d)
47. (b, c, d)
48. (b, c,)
49. (c, d)
50. (b, d)
51. (a, c)
52. (a, b, c, d)
53. (a, c, d)
54. (a, c)
55. (a, c)
56. (a, b, d)
57. (b, d)
58. (b, c)
59. (b) **60.** (a) **61.** (c) **62.** (a)
63. (d) **64.** (c) **65.** (b) **66.** (a)
67. (c) If +ve charge is displaced along x-axis, then net force will always act in a direction opposite to that of displacement and the test charge will always come back to its original position.
68. (d) $q_d = e,\ m_d = 2m_p = 2m$

$q_\alpha = 2e,\ m_\alpha = 4m_p = 4m$

$F_1 = F_\alpha = eE,\ F_2 = F_\alpha = 2eE \neq F_1$

Further, $a_1 = \frac{F_1}{2m} = \frac{eE}{2m}$

and $a_2 = \frac{F_2}{2m} = \frac{2eE}{4m} = \frac{eE}{2m} = a_1$
69. (d) Electric field at any point depends on presence of all charges.
70. (a) No. of lines entering the surface = No. of lines leaving the surface.
71. (d) Charge distribution on each surface makes both capacitor of same potential difference hence charge will not flow.
72. (d) The charge on each of two facing surfaces will be zero.
73. (d) Potential and potential energy are different quantities and cannot be equated.
74. (b) **75.** (d) **76.** (a) **77.** (d)
78. $E = \frac{dV}{dr} = \frac{12}{3\times10^{-3}} = 4\times10^3$ N/C.
79. Charge on gold nucleus = q = Ze = $79 \times 1.6 \times 10^{-19}$

$$V = \frac{kq}{r} = \frac{9\times10^9\times79\times1.6\times10^{-19}}{6.6\times10^{-15}} = 1.724\times10^7\text{ V}.$$

80. $V=\frac{kq}{r}=\frac{9\times10^{9}\times4\times10^{-7}}{0.1}=3.6\times10^{4}\,V.$

81. $E=\frac{kq}{r^{2}}=32$ and $V=\frac{kq}{r}=16$

$r=\frac{16}{32}=0.5\text{ m}\ \therefore\ \frac{kq}{0.5}=16\ \Rightarrow q=8.89\times10^{-10}\,C$

82. $C_1=\frac{\varepsilon_0 A}{d}=10\text{ pF},\ C_2=\frac{k\varepsilon_0 A}{d/2}$

$=10\times10\times2\ \mu F=200\ \mu F.$

83. $C=\frac{\varepsilon_0 A}{d}=\frac{8.85\times10^{-12}\times6\times10^{-3}}{3\times10^{-3}}=17.7\ \mu F$

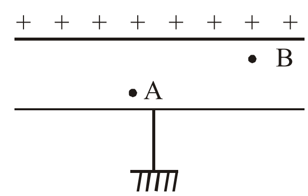
$q=CV=17.7\times10^{-12}\times200=3.54\times10^{-9}\,C.$

84. Energy $=\frac{1}{2}CV^{2}=\frac{1}{2}\times470\times10^{-6}\times(20)^{2}=94\times10^{-3}\,J.$

85. For an electric dipole, $F\propto\frac{1}{r^{3}}$

$\therefore$ New force, $F^{1}=\frac{F}{2^{3}}=\frac{F}{8}.$

86.



Electric field between the plates of a capacitor is uniform that is constant at every point $\left(E=\frac{\sigma}{\varepsilon_0}\right)$.

$\therefore$ Electric field is same at A and B.

Chapter

7 ALTERNATING CURRENT

INTRODUCTION

The alternating currents play an important role in the present day technology and industry. The transmission of electrical power over the long distances becomes very much easier and more economical with the alternating currents than the direct currents. The circuits used in the modern communication systems, including the radio and television, computer systems, and so on, make an extensive use of the alternating currents. The alternating currents are involved in the many life processes. The electrocardiography, i.e., the detection and study of alternating currents induced in the surrounding tissues due to the heart beating, provides a valuable information about the health and pathology of heart. The electroencephalograms, being the recordings of alternating currents in the brain, provide a vital information regarding the functioning of brain.

ALTERNATING CURRENT (A.C.)

An alternating current is one which periodically changes in magnitude and direction. It increases from zero to a maximum value, then decreases to zero and reverses in direction, increases to a maximum in this direction and then decreases to zero.

The alternating currents change both in magnitude and direction periodically. They have the various different waveforms, or waveshapes, e.g., sinusoidal, square, triangular, sawtoothed, and so on, depending on their applications.

The alternating currents, in the normal use, have the sinusoidal waveform and represented analytically as

$$i = I_0 \sin(\omega t)$$

where i is the instantaneous value, I_0 is the peak value, or amplitude, $\omega = 2\pi/T = 2\pi f$ is the angular frequency, T being the time period and f being the frequency, and ωt is the phase angle.

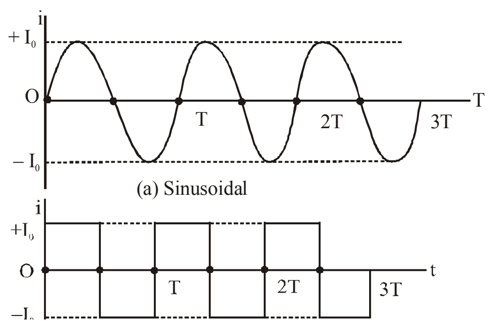


Fig. 7.1

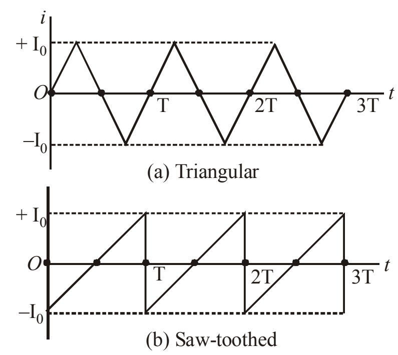
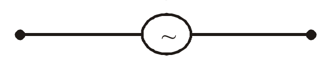


Fig 7.2

The alternating currents are generated in the circuits energised by the sources of alternating e.m.f., or voltage, such as, the ac generators and electronic oscillators, represented graphically by the symbol 

The sinusoidal e.m.fs, or voltages, are represented analytically as

$$V = V_0 \sin(\omega t)$$

where V is the instantaneous value, V_0 is the peak value, or amplitude, and $\omega = 2\pi/T = 2\pi f$ is the angular frequency, T being the time period and f being the frequency, and ωt is the phase angle.

ADVANTAGES OF A.C. OVER D.C

(i) The generation of A.C. is cheaper than that of D.C.
(ii) Alternating voltage can be easily stepped up or stepped down by using a transformer.
(iii) A.C. can be easily converted into D.C. by rectifier.
(iv) It can be transmitted to a long distance without appreciable loss.

AVERAGE OR MEAN VALUE OF ALTERNATING CURRENT

The average or mean value of sinusoidal current $i = I_0 \sin(\omega t)$ over a complete cycle is

$$I_{av} = \frac{1}{T}\int_0^T i\,dt = \frac{1}{T}\int_0^T I_0 \sin(\omega t)dt = \frac{1}{T}\left[\frac{-I_0 \cos(\omega t)}{w}\right]_0^T$$

$$= \frac{1}{T}\left[\frac{-I_0 \cos(2\pi)}{\omega} + \frac{I_0 \cos(0)}{\omega}\right] = 0$$

It is zero because the integral represents the area between the curve and time axis over a complete cycle and this area is negative as much as it positive. This is the reason that if a sinusoidal current is sent through a moving-coil galvanometer, it reads zero.
The non-zero average, or mean, value of sinusoidal current $i = I_0 \sin(\omega t)$ over a half-cycle is

$$I_{av} = \frac{2}{T}\int_0^{T/2} i\,dt = \frac{2}{T}\int_0^{T/2} I_0 \sin(\omega t)dt = \frac{2}{T}\left[\frac{-I_0 \cos(\omega t)}{\omega}\right]_0^{T/2}$$

$$= \frac{2}{T}\left[\frac{-I_0 \cos \pi}{\omega} + \frac{I_0 \cos(0)}{\omega}\right] = \frac{2I_0}{\pi} \approx 0.637 I_0$$

This average value is the height of rectangle, shown shaded in the figure, having its area equal to the area under one loop of the *sine* curve.

Similarly, the non-zero average, or mean, value of sinusoidal e.m.f., or voltage, $v = V_0 \sin(\omega t)$ over a half cycle is

$$V_{av} = \frac{2V_0}{\pi} \approx 0.637 V_0$$

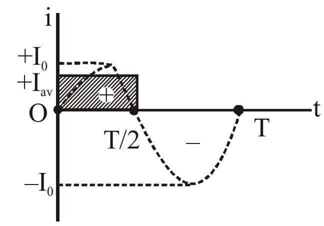


Fig. 7.3

ROOT-MEAN SQUARE (RMS) VALUE OF ALTERNATING CURRENT

Most of the ac meters are calibrated to record not the peak value of alternating current, or voltage, but the root-mean-square (rms) value, i.e., the square root of the average, or mean, of the square of current, or voltage. Because i^2 is always positive and the graph of i^2 against the time t lies above the t-axis, as shown, the average of i^2 is never zero, even when the average of i itself is zero.

The average value of i^2, called the mean square current, over a complete cycle is

$$I^2_{\text{rms}} = I^2 = \frac{1}{T}\int_0^T i^2 dt = \frac{1}{T}\int_0^T I_0^2 \sin^2(\omega t) dt = \frac{1}{T}\int_0^T \frac{I_0^2}{2}[1 - \cos(2\omega t)]\, dt$$

$$= \frac{I_0^2}{2T}\left[t - \frac{\sin(2\omega t)}{2\omega}\right]_0^T \qquad = \frac{I_0^2}{2T}\left[T - \frac{\sin(4\pi)}{2\omega} + \frac{\sin(0)}{2\omega}\right] = \frac{I_0^2}{2}$$

which is the height of rectangle, shown shaded in the figure.

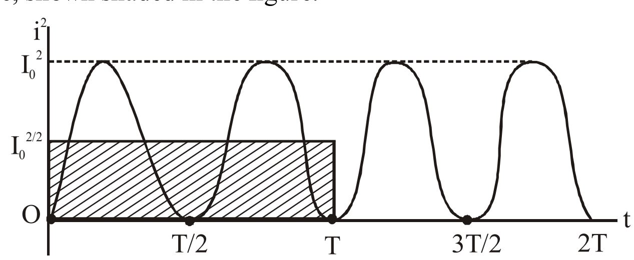


Fig. 7.4

Its square root gives the root-mean-square (rms) current,

$$\text{i.e., } I_{\text{rms}} \equiv I = \frac{I_0}{\sqrt{2}} \approx 0.707 I_0$$

Similarly, the root-mean-square (rms) value of a sinusoidal voltage

$$V_{\text{rms}} \equiv V = \frac{V_0}{\sqrt{2}} \approx 0.707 V_0$$

When a sinusoidal current $i = I_0 \sin(\omega t)$ flows through a resistance R, the average rate of heating during a complete cycle is given by

$$P = \frac{1}{T}\int_0^T i^2 R\, dt = R\left[\frac{1}{T}\int_0^T i^2 dt\right] = R\,(I_{\text{rms}})^2$$

which also equals the rate of heating, when a dc of the value I_{rms} flows through the same resistance R.

For this reason, I_{rms} is also called the **effective value, or virtual value, or dc value of ac.**

The currents and voltages in the power distribution systems are always quoted in terms of their *rms* values. Thus, when we speak of our house-hold power supply as '220V ac', we mean to say that the *rms* voltage is 220V. Then, the peak voltage is

$$V_0 = \sqrt{2} V_{\text{rms}} = \sqrt{2} \times 220 \approx 311 V$$

i.e., the voltage varies between +311V and –311V in a complete cycle. For the reason, an ac of 220V is more dangerous than a dc of 220V.

ILLUSTRATION : 7.1

If a domestic appliance draws 2.5 A from a 220-V, 60- Hz power supply, find

(a) the average current

(b) the average of the square of the current

(c) the current amplitude

(d) the supply voltage amplitude.

SOLUTION :

(a) The average of sinusoidal AC values over any whole number of cycles is zero.

(b) RMS value of current = I_{rms} = 2.5 A

$$\therefore \quad (I^2)_{av} = (I_{rms})^2 = 6.25 A^2$$

(c) $I_{rms} = \dfrac{I_m}{\sqrt{2}}$

$\therefore$ Current amplitude $= \sqrt{2} I_{rms} = \sqrt{2}(2.5\,A) = 3.5$ A

(d) $V_{rms} = 220V = \dfrac{V_m}{\sqrt{2}}$

$\therefore$ Supply voltage amplitude $V_m = \sqrt{2}(V_{rms}) = \sqrt{2}(220V) = 311$ V.

ILLUSTRATION : 7.2

What is the ratio of mean value over half cycle to r.m.s. value of A.C.?

SOLUTION :

We know that $I_{rms} = I_0/\sqrt{2}$ and $I_m = 2I_0/\pi$

$$\therefore \quad \frac{I_m}{I_{rms}} = \frac{2\sqrt{2}}{\pi}$$

Keep in Memory:

(i) Time period : The time taken by A.C. to go through one cycle of changes is called its time period. It is given as $T = \dfrac{2\pi}{\omega}$

(ii) Phase : Phase is that property of wave motion which tells us the position of the particle at any instant as well as its direction of motion. It is measured either by the angle which the particle makes with the mean position or by fraction of time period.

(iii) Phase Angle : Angle associated with the wave motion (sine or cosine) is called phase angle.

(iv) Lead : Out of the current and e.m.f the one having greater phase angle will lead the other e.g. in equation $i = i_0 \sin\left(\omega t + \dfrac{\pi}{2}\right)$ *and* $e = e_0 \sin \omega t$*, the current leads the e.m.f. by an angle* $\dfrac{\pi}{2}$.

(v) Lag : Out of current and e.m.f. the one having smaller phase angle will lag the other. In the above equations, the e.m.f lags the current by $\dfrac{\pi}{2}$.

RESISTANCE OFFERED BY VARIOUS ELEMENTS (RESISTOR, INDUCTOR, CAPACITOR) TO A.C.

Alternating current in a circuit may be controlled by resistance, inductance and capacitance, while the direct current is controlled only by resistance.

(i) **Impedance (Z) :** In alternating current circuit, the ratio of e.m.f. applied and consequent current produced is called the impedance and is denoted by Z, i.e., $\left[Z = \frac{E}{I} = \frac{E_0}{I_0} = \frac{E_{rms}}{I_{rms}}\right]$

Physically impedance of ac circuit is the hindrance offered by resistance alongwith either inductance or capacitance or both in the circuit to the flow of ac through it. Its **S.I.unit** is ohm.

(ii) **Reactance (X) :** The hindrance offered by inductance or capacitance or both to the flow of ac in an ac circuit is called reactance and is denoted by X. Thus when there is no ohmic resitance in the ciruit, the reactance is equal to impedance. The reactance due to inductance alone is called inductive reactance and is denoted by X_L, while the reactance due to capacitance alone is called the capacitive reactance and is denoted by X_C. Its **S.I.unit** is also ohm.

(iii) **Admittance.** The inverse of impedance is called the admittance and is denoted by Y, i.e., $Y = \frac{1}{Z}$

Its **S.I.unit** is ohm^{-1}.

IMPEDANCES AND PHASES OF AC CIRCUIT CONTAINING DIFFERENT ELEMENTS

As already pointed out that in an ac circuit the current and applied e.m.f.'s are not necessarily in same phase. The applied e.m.f. (E) and current produced (*I*) may be expressed as

$E = E_0 \sin \omega t$ and $I = I_0 \sin (\omega t + \phi)$ with $I_0 = E_0/Z$

where E_0 and I_0 are peak values of alternating e.m.f. and current.

(i) Circuit containing only resitance (R): Consider a pure ohmic resistor (zero inductance) of resistance R connected to an alternating source of e.m.f. $E = E_0 \sin \omega t$. Then current I in the circuit is

$$I = \frac{E}{R} = \frac{E_0 \sin \omega t}{R} = I_0 \sin \omega t \quad \text{where } I_0 = E_0/R$$

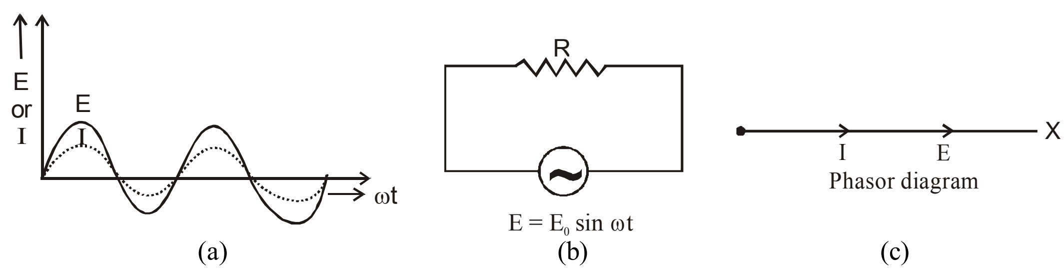


Fig. 7.5

Comparing this with standard equation, we note that

Impedance of circuit, Z = R and phase difference between current and e.m.f. = 0.

Hence we conclude that in a purely resistive ac circuit the current and voltage are in same phase and impedance of circuit is equal to the ohmic resistance.

(ii) Circuit contianing only inductance(L): Consider a pure inductor (zero ohmic resistance) of inductance L connected to an alternating source of e.m.f. $E = E_0 \sin \omega t$. Then current I in the circuit is

$$I = I_0 \sin\left(\omega t - \frac{\pi}{2}\right) \text{ where } I_0 = \frac{E_0}{\omega L}$$

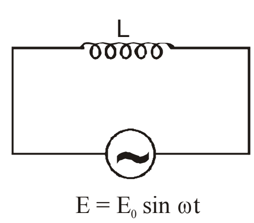


Fig. 7.6

Comparing this with standard equation, we know that $Z = \omega L$ and $\phi = \pi/2$.

Hence we conclude that *in a purely inductive circuit the current lags behind the applied voltage by an angle π/2 and the impedance to the circuit is* ωL and this is called as **inductive reactance.**

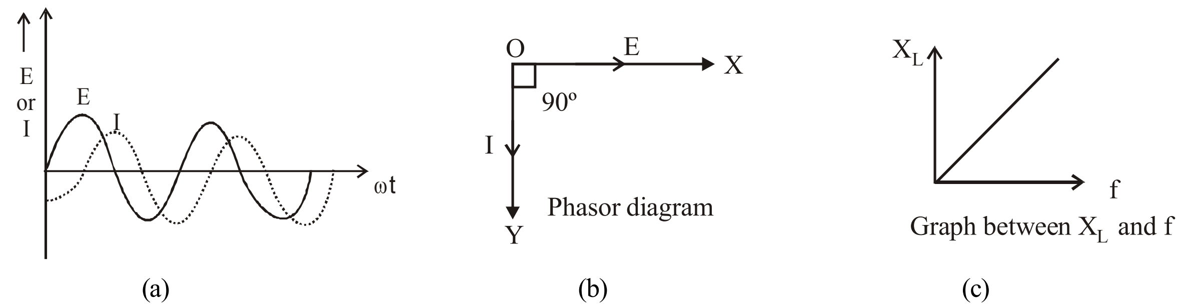


Fig. 7.7

(iii) Circuit containing only capacitance(C): Consider a capacitor of capacitance C connected to an alternating source of e.m.f., $E = E_0 \sin \omega t$

Then the current through C is given by, $I = I_0 \sin\left(\omega t + \frac{\pi}{2}\right)$

Comparing this with standard equation, we find that $X_C = 1/\omega C$ and $\phi = +\pi/2$

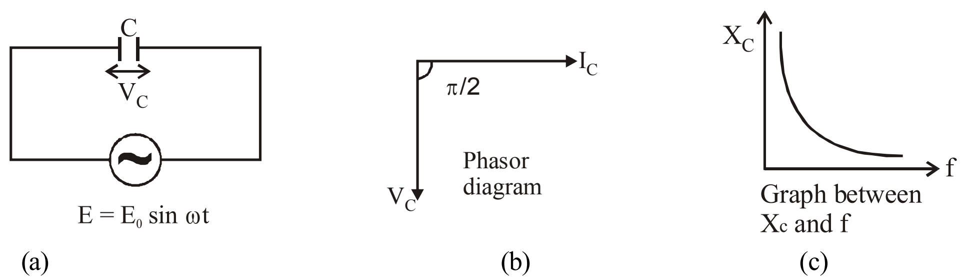


Fig. 7.8

Hence we conclude that in a purely capacitive circuit the current leads the applied e.m.f. by an angle π/2 and the impedance of the circuit is 1/ωC and this is known as capacitive reactance $Z = X_C = \frac{1}{\omega C}$.

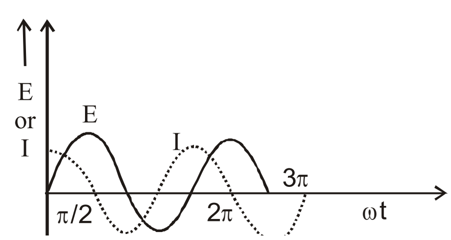


Fig. 7.9

CIRCUIT CONTAINING RESISTANCE, INDUCTANCE AND CAPACITANCE IN SERIES (SERIES LCR CIRCUIT)

Consider a circuit containing a resistance R, inductance L and capacitance C in series having an alternating e.m.f. $E = E_0 \sin \omega t$. Let **I** be the current flowing in circuit. V_R, V_L and V_C are respective potential differences across resistance R, inductance L and capacitance C.

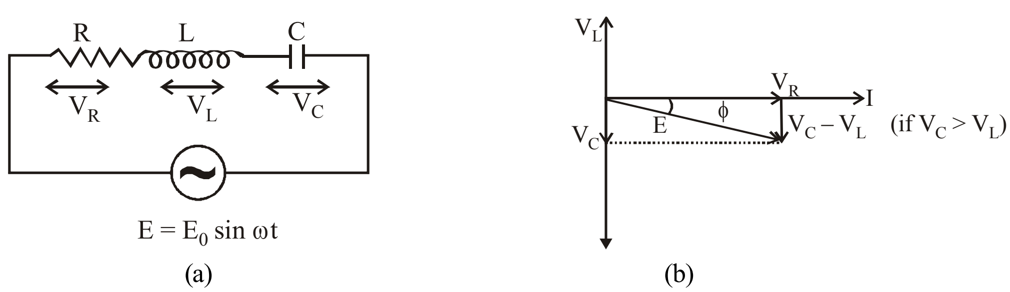


Fig. 7.10

The p.d. V_R is in phase with current $\mathbf{I}$. The p.d. V_C lags behind the current by angle $\pi/2$. The p.d. V_L leads the current by angle $\pi/2$.

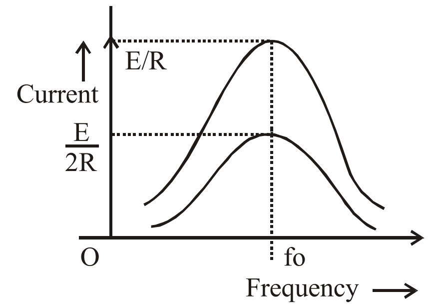


Fig. 7.11

$\therefore$ Resultant applied e.m.f., $E = \sqrt{[V_R^2 + (V_C - V_L)^2]}$

i.e., $E = \sqrt{\{(R\,\mathbf{I})^2 + (\mathbf{I}X_C - \mathbf{I}X_L)^2\}}$

$\therefore$ Impedance, $Z = \dfrac{E}{I} = \sqrt{\{R^2 + (X_C - X_L)^2\}}$

The phase leads of current over applied e.m.f. is given by

$$\tan\phi = \frac{V_C - V_L}{V_R} = \frac{IX_C - IX_L}{RI} = \frac{X_C - X_L}{R}$$

i.e., $\phi = \tan^{-1}\left(\dfrac{X_C - X_L}{R}\right)$

It is concluded that

(a) If $X_C > X_L$, the value of ϕ is positive, i.e., current leads the applied e.m.f..

(b) If $X_C < X_L$, the value of ϕ is negative, i.e., current lags behind the applied e.m.f..

(c) If $X_C = X_L$, the value of ϕ is zero, i.e., current and e.m.f. are in same phase. This is called the case of **resonance** and resonant frequency for condition $X_C = X_L$, is given by

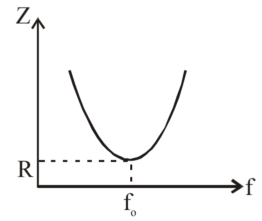


Fig. 7.12

$$\frac{1}{\omega C} = \omega L \quad \text{i.e.,} \quad \omega = \frac{1}{\sqrt{LC}}$$

$$\therefore \quad f_o = \omega/2\pi = \frac{1}{2\pi\sqrt{(LC)}}.$$

Thus the resonant frequency depends on the product of L and C and is independent of R.

At resonance, impedance is minimum, $Z_{min} = R$ and current is maximum $I_{max} = \dfrac{E}{Z_{min}} = \dfrac{E}{R}$

It is interesting to note that before resonance the current leads the applied e.m.f., at resonance it is in phase, and after resonance it lags behind the e.m.f.. LCR series circuit is also called as **acceptor circuit** and parallel LCR circuit is called **rejector circuit.**

ILLUSTRATION : 7.3

Obtain the resonant frequency ω_r of a series LCR circuit with L = 2.0 H, C = 32 μF and R = 10Ω. What is the Q-value of this circuit?

SOLUTION :

Given, $L = 2H$, $C = 32\ \mu F = 32 \times 10^{-6}$ F, $R = 10\Omega$, $\omega_r = ?$, $Q = ?$

By relation,

$$\omega_r = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{2 \times 32 \times 10^{-6}}} = \frac{10^3}{8} = 125 \text{ rad s}^{-1}.$$

Quality factor (Q-value) $\dfrac{\omega_r L}{R} = \dfrac{125 \times 2}{10} = 25$

RESONANCE

When the impedance of the circuit is maximum i.e., Z = R or admittance of the circuit becomes minimum $\left(Y = G = \dfrac{1}{R}\right)$, *condition of resonance occurs in parallel resonance circuit.*

In this condition $X_L = X_C$

or $\omega_r = \frac{1}{\sqrt{LC}}$; $f_r = \frac{1}{2\pi\sqrt{LC}}$

In parallel circuit at resonance :

- $I_{OL} = I_{OC}$, the phase $\phi = 0°$, $\cos\phi = 1$
- The peak current is minimum
- The quality factor $Q = \frac{R}{\omega_r L}$
- The bandwidth $BW = \frac{f_r}{Q}$

Practical LCR Parallel Resonant Circuit

The inductance coil has some resistance R and it is connected in parallel to a capacitor C.

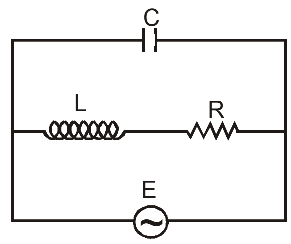


Fig. 7.13

For this circuit, the impedance is obtained from $\frac{1}{Z} = Y$,

where *the admittance is* $Y = \sqrt{\frac{(1-\omega^2 LC)^2 + (\omega CR)^2}{R^2 + (\omega L)^2}}$

The resonance occurs when the admittance is minimum.

Resonance frequency $\omega_r = \frac{1}{\sqrt{LC}}\left(1 - \frac{R^2 C}{L}\right)^{1/2}$

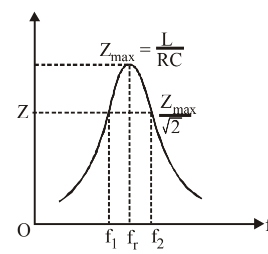


Fig. 7.14

or $\omega_r = \sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}$ or, $f_r = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}$

If R = 0 in fig. then it becomes a parallel LC circuit.

Resonance occurs at $\omega_r = \frac{1}{\sqrt{LC}}$; $f_r = \frac{1}{2\pi\sqrt{LC}}$

If $\frac{1}{LC} - \frac{R^2}{L^2}$ has negative value then resonance does not occurs. A parallel LCR circuit offers maximum impedance at $f = f_r$. The impedance decreases for $f < f_r$ and $f > f_r$. Since the impedance between frequencies f_1 and f_2 is large, current between this band is small.

The parallel LCR circuit is therefore, also called **Band Rejector circuit**. f_1 and f_2 are half power frequencies and impedance in between these two is $\frac{Z \geq Z_{max}}{\sqrt{2}}$.

Choke Coil

A choke coil is simply an inductor with a large self-inductance and negligible resistance (zero in ideal case). It is used in A.C. circuits for reducing current without consuming power.

The choke coil is put in series with the electrical device, such as fluorescent tube requiring a low value of current. The inductive reactance decreases the current. Since the alternating e.m.f. leads the current by phase angle $\frac{\pi}{2}$.

The average power consumed by the choke coil $P_{av} = E_v I_v \cos\frac{\pi}{2} = 0$.

However, a practical inductance possesses a small resistance i.e., a practical inductance may be treated as a series combination of inductance L and a small resistance r.

Average power consumed in a practical inductance $P_{av} = E_v I_v \times \dfrac{r}{\sqrt{r^2 + \omega^2 L^2}}$

For practical inductance *power factor* (cos ϕ) = $\dfrac{r}{\sqrt{r^2 + \omega^2 L^2}}$

Uses : In a.c. circuits, a choke coil is used to control the current in place of a resistance. If a resistance is used to control the current, the electrical energy will be wasted in the form of heat. A choke coil decreases the current without wasting electrical energy in the form of heat.

TRANSFORMER

It is a device used for transforming a low alternating voltage of high current into a high alternating voltage of low current and vice versa, without increasing power or changing frequency.

Principle : It works on the phenomenon of mutual induction.

Construction: It has three main parts described below:

1. **Laminated core C:** It is of sand-mixed iron in shell type, it has more resistance due to laminations and mixing of sand. It is done to reduce eddy current in the core and minimize its heating.
2. **Primary coil P :** It is a coil of enamelled copper wire wrapped over the central arm of the core and is insulated by varnish.
3. **Secondary coil S :** It is also a coil of enamelled copper wire. It is wrapped over the primary coil and insulated by wax paper. Transformed alternating voltage is obtained from it. It forms output section of the transformer.

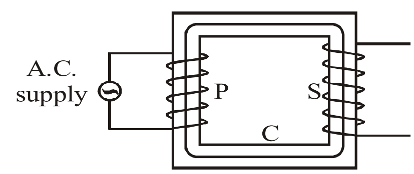


Fig. 7.15

If a low voltage is to be transformed into a high voltage, then the number of turns in secondary is more than those in primary. The transformer is called a **step up transformer.**

If a high voltage is to be transformed into a low voltage, then the number of turns in secondary is less than those in primary. The transformer is called a **step-down transformer.**

Transformation ratio of the transformer,

$$K = \frac{Number\ of\ turns\ in\ secondary\ (N_s)}{Number\ of\ turns\ in\ primary\ (N_p)}$$

K > 1, for step-up transformer.

K < 1, for step-down transformer.

The whole arrangement is kept immersed in a special oil called transformer oil, taken in metallic cans. The oil provides insulation as well as cooling.

Working : As voltage applied to the primary is alternating, it produces a continuous change in magnetic flux in primary as well as in secondary. Due to mutual induction, an e.m.f. is induced in secondary. It is higher or lower than that induce in primary depending upon whether the transformer is a step-up or step-down transformer. The induced e.m.f. in secondary gives output voltage.

Theory : An alternating e.m.f. E_p is applied across the primary which produces current I_p in the primary circuit and a current I_s in the secondary circuit. The currents in the coils produce a magnetization in the soft-iron core and there is a corresponding magnetic field B inside the core. The field due to magnetization of the core is large as compared to the field due to the current in the coils. We assume that the field is constant in magnitude everywhere in the core and hence, its flux (BA) through each turn is same for the primary as well as for the secondary coil.

Let the flux through each turn be Φ.

The emf induced in the primary, $E_P = -N_p \dfrac{d\Phi}{dt}$

and induced emf in the secondary, $E_S = -N_s \times \dfrac{d\Phi}{dt}$

If we neglect the resistance in the primary circuit, Kirchhoff's loop law applied to the primary circuit which gives,

$$E_p = N_p \frac{d\Phi}{dt} \qquad ......(i)$$

$$\text{Also, } E_s = -N_s \frac{d\Phi}{dt} \qquad ......(ii)$$

From eqs. (i) and (ii), $E_s = -\frac{N_s}{N_p} E_p$

The minus sign shows that E_s is 180° out of phase with E_p.
Equ^{n}s. (i) and (ii) are valid for all values of currents in the primary and the secondary circuits. If there is no loss of power in output and input circuit then, **input power = output power**

i.e., $E_p \times I_p = E_s \times I_s$ or, $\frac{I_p}{I_s} = \frac{E_s}{E_p} = \frac{N_s}{N_p}$

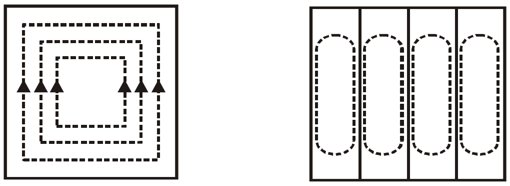
But in practice there is always energy loss so, input power > output power.
Hence, $E_p \times I_p > E_s \times I_s$

Energy loss in a transformer :

(i) Copper loss : Energy lost in winding of the transformer is known as copper loss. Primary and secondary coils of a transformer are generally made of copper wires. These copper wires have resistance (R). When current (I) flows through these wires, power loss (I^2R) takes place. This loss appears as the heat produced in the primary and secondary coils. Copper loss can be reduced by using thick wires for the windings.

(ii) Flux loss : In actual transformer, the coupling between primary and secondary coil is not perfect. It means that magnetic flux linked with the primary coil is not equal to the magnetic flux linked with secondary coil, so a certain amount of electric energy supplied to the primary coil is wasted.

(iii) Eddy current loss : *When a changing magnetics flux links with the iron core of the transformer, eddy currents are set up.* These eddy currents produce heat which leads to the wastage of energy. This energy loss is reduced by using laminated core.
Eddy currents are reduced in a laminated core because their paths are broken as compared to solid core as shown in figure.



Solid core Laminated core

Fig. 7.16

(iv) Hysteresis loss : When alternating current passes through the primary coil, core of the transformer is magnetized and demagnetised over a complete cycle. Some energy is lost in magnetising and de-magnetising the iron core. The energy loss in a complete cycle is equal to area of the hysteresis loop.
This energy loss can be minimized by using suitable material having narrow hysteresis loop for the core of a transformer.

(v) Loss due to vibration of core or humming loss : A transformer produces humming noise due to magnetostriction effect. Some electrical energy is lost in the form of mechanical energy to produce vibration in the core.

Efficiency of a Transformer

In an ordinary transformer, there is some loss of energy due to coil resistance, hysteresis in the core, eddy currents in the core etc. The percentage efficiency of a transformer is defined as

i.e., $\eta\,\% = \frac{\text{Output power}}{\text{Input power}} \times 100 = \frac{V_S I_S}{V_P I_P} \times 100$

Efficiency for an ideal transformer is 100% but of practical transformer lies between 70% – 90%.

Uses of Transformer

A transformer is used in almost all ac operation.

(i) In voltage regulators for TV, refrigerator, computer, air conditioner etc.
(ii) In the induction furnaces.
(iii) Step down transformer is used for welding purposes.
(iv) In the transmission of ac over long distance.
(v) Step down and step up transformers are used in electrical power distribution.

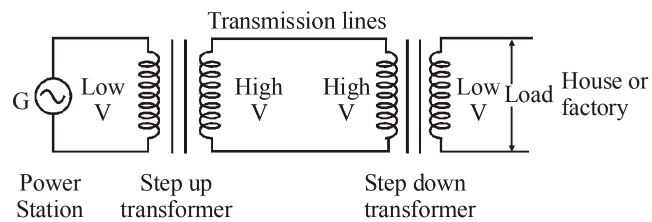


Fig. 7.17

(vi) Audio frequency transformers are used in radiography, television, radio, telephone etc.

(vii) Radio frequency transformers are used in radio communication.

The ease with which voltages can be stepped UP or down with a transformer is the principal reason that most electric power is AC rather then DC

Fig. 7.18 Voltage generated in power stations is stepped up with transformers prior to being transferred across country by overhead cables. Then other transformers reduce the voltage before supplying it to homes, offices, and factories.

ILLUSTRATION : 7.4

A lossless transformer steps down 220 V to 22 V and operates a device having an impedance of 220 Ω. What is the primary current ?

SOLUTION :

In the lossless transformer, we are given that

$$V_P = 220\,V, V_S = 22\,V, I_S = \frac{V_s}{R} = \frac{22}{220} = 0.1A : I_p = ?$$

$$\frac{V_S}{V_P} = \frac{I_P}{I_S} \Rightarrow \frac{22}{220} = \frac{I_P}{0.1} \Rightarrow I_P = 0.01A$$

ILLUSTRATION : 7.5

In a transformer, the primary and secondary have 1000 and 3000 turns, respectively. If the primary is connected across an ac source of 80V, then what will be the voltage across each turn of the secondary?

SOLUTION :

Given: $N_p = 1000; N_s = 3000$ V_p 80v; $V_s = ?$

In the transformer, we have

$$\frac{V_S}{V_P} = \frac{N_S}{N_P} \Rightarrow \frac{V_S}{80} = \frac{3000}{1000} \Rightarrow V_S = 240\text{ V}$$

and then, the voltage across each turn of secondary becomes $\frac{V_S}{N_S} = \frac{240}{3,000} = 0.08\text{ V}$

ILLUSTRATION : 7.6

A transformer is used to step-down a voltage from 220 V to 11V. If the primary and secondary currents are 5A and 90A, respectively, what is the efficiency of transformer?

SOLUTION :

Here, $V_p = 220V; V_S = 11V\ I_p = 5A; I_2 = 90A$

The efficiency of transformer

$$\eta = \frac{V_S I_S}{V_P I_P} \times 100\% = \frac{11 \times 90}{220 \times 5} \times 100\% = 90\%$$

MISCELLANEOUS SOLVED EXAMPLES

1. **A current of 4A flows in a coil when connected to a 12V dc source. If the same coil is connected to a 12V, 50 rad/s a.c. source, a current of 2.4A flows in the circuit. Determine the inductance of the coil.**

Sol. A coil consists of an inductance (L) and a resistance (R).
In dc only resistance is effective. Hence,

$$R = \frac{V}{i} = \frac{12}{4} = 3\Omega$$

In ac, $i_{rms} = \frac{V_{rms}}{Z} = \frac{V_{rms}}{\sqrt{R^2 + \omega^2 L^2}}$ $\quad \therefore \; L^2 = \frac{1}{\omega^2}\left[\left(\frac{V_{rms}}{i_{rms}}\right)^2 - R^2\right]$

$$\Rightarrow L = \frac{1}{\omega}\sqrt{\left(\frac{V_{rms}}{i_{rms}}\right)^2 - R^2} = \frac{1}{50}\sqrt{\left(\frac{12}{2.4}\right)^2 - (3)^2} = 0.08 \text{ henry}$$

2. **When a series combination of inductance and resistance are connected with a 10V, 50Hz a.c. source, a current of 1A flows in the circuit. The voltage leads the current by a phase angle of π/3 radian. Calculate the values of resistance and inductive reactance.**

Sol. As we know, $Z = \sqrt{R^2 + X_L^2} = \frac{E}{I} = \frac{10}{1} = 10\Omega$

$$\frac{X_L}{R} = \tan\phi = \tan\frac{\pi}{3} = \sqrt{3} \Rightarrow X_L = \sqrt{3}R$$

$$Z = \sqrt{R^2 + 3R^2} = 10$$

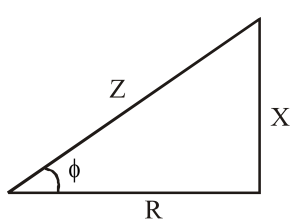
$$\Rightarrow 2R = 10 \Rightarrow R = 5\Omega \text{ and } X_L = \sqrt{3}R = 5\sqrt{3}\,\Omega$$

3. **For a series LCR circuit I = 100 sin (100πt – π/3) mA and V = 100 sin (100πt) volt, then**
   (a) calculate resistance and reactance of circuit.
   (b) find average power loss.

Sol. (a) Impedance, $Z = \frac{V_0}{I_0} = \frac{100}{100 \times 10^{-3}} = 1000\,\Omega$

Resistance, $R = Z\cos\phi = 1000\cos\left(\frac{\pi}{3}\right) = 500$ ohm

Reactance, $X = Z\sin\phi = 1000\sin\left(\frac{\pi}{3}\right) = 500\sqrt{3}$ ohm



(b) Average power loss, $P_{av} = V_{rms}I_{rms}\cos\phi$

$$= \frac{100}{\sqrt{2}} \times \frac{100}{\sqrt{2} \times 1000} \times \cos\left(\frac{\pi}{3}\right) = 5 \times \frac{1}{2} = 2.5 \text{ watts}$$

4. **A R-L circuit draws a power of 440W from a source of 220V, 50Hz. The power factor of the circuit is 0.5. To make the power factor of the circuit as 1.0, what capacitance will have to be connected with it ?**

Sol. $\because$ Power $P = VI\cos\phi = \frac{V^2}{Z}\cos\phi$

$$\therefore \quad Z = \frac{V^2 \cos\phi}{P} = \frac{(220)^2(0.5)}{(440)} = 55\,\Omega$$

Also power factor

$$\cos\phi = \frac{R}{Z} \Rightarrow R = Z\cos\phi = (55)(0.5) = 27.5\,\Omega$$

$$\therefore \quad X_L = \sqrt{Z^2 - R^2} = \sqrt{(55)^2 - \left(\frac{55}{2}\right)^2} = \frac{55\sqrt{3}}{2}\Omega$$

when power factor is 1.0 then $X_L = X_C$

$$\text{so } X_L = \frac{1}{\omega C} \Rightarrow C = \frac{1}{\omega X_L} = \frac{1}{(314)\left(\frac{55\sqrt{3}}{2}\right)} = 6.68 \times 10^{-5}\,\text{F}$$

5. A series LCR circuit with L = 0.12 H, C = 480 nF, R = 23Ω is connected to a 230V variable frequency supply find :
(a) Source frequency for which current is maximum.
(b) Q-factor of the given circuit.

Sol. (a) we know, $\omega = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{0.12 \times 480 \times 10^{-9}}} = \frac{10^5}{24}$ rad / s

$$\Rightarrow \quad f = \frac{1}{2\pi} \times \frac{10^5}{24} = 6.63 \times 10^2\,\text{Hz}$$

(b) Q-factor, $\frac{X_L}{R} = \frac{\omega L}{R} = \frac{10^5 \times 0.12}{24 \times 23} = \frac{10^3}{46} = 21.7$

6. A variable frequency 230V alternating voltage source is connected across a series combination of L = 5.0H, C = 80μF and R = 40Ω. Calculate :
(a) The angular frequency of the source at resonance.
(b) Amplitude of current at resonance frequency.

Sol. (a) Angular frequency at resonance

$$\omega_r = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{5.0 \times 80 \times 10^{-6}}} = \frac{10^2}{2} = 50 \text{ rad / s}$$

(b) Amplitude of current at resonance $\quad I_m = \frac{V}{R} = \frac{230\sqrt{2}}{40} = 8.13$ A

7. A transformer having efficiency 90% is working on 100 V and at 2.0 kW power. If the current in the secondary coil is 5A, calculate (i) the current in the primary and (ii) voltage across the secondary coil.

Sol. Here, $\eta = 90\% = \frac{9}{10}$, $I_s = 5$A, $E_p = 100$ V.

$E_pI_p = 2\text{ kW} = 2000\text{ W}$

(i) $E_pI_p = 2000$ W

$$\therefore I_p = \frac{2000}{E_p} \quad \text{or} \quad I_p = \frac{2000}{100} = 20\,\text{A}$$

(ii) $\eta = \frac{\text{Output power}}{\text{Input power}} = \frac{E_sI_s}{E_pI_p}$

$$\text{or, } E_sI_s = \eta \times E_pI_p = \frac{9}{10} \times 2000 = 1800\,\text{W} \qquad \therefore E_S = \frac{1800}{I_s} = \frac{1800}{5} = 360\,\text{Volt}$$

EXERCISE

DIRECTIONS (Qs. 1-23) : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. An inductor, a resistor and a capacitor are joined in series with an AC source. As the frequency of the source is slightly increased from a very low value, the reactance of the
(a) inductor increases
(b) reasistor increases
(c) capacitor increases
(d) circuit increases

2. An A.C. source is connected to a resistive circuit. What is true of the following?
(a) current leads ahead of voltage in phase
(b) current lags behind voltage in phase
(c) current and voltage are in same phase
(d) any of the above may be true depending upon the value of resistance.

3. The capacitive reactance in an A.C. circuit is
(a) effective resistance due to capacity
(b) effective wattage
(c) effective voltage
(d) none of the above

4. The power factor in a circuit connected to an A.C. The value of power factor is
(a) unity when the circuit contains an ideal inductance only
(b) unity when the circuit contains an ideal resistance only
(c) zero when the circuit contains an ideal capacitance only
(d) None of these

5. Current in a circuit is wattless if
(a) inductance in the circuit is zero
(b) resistance in the circuit is zero
(c) current is alternating
(d) resistance and inductance both are zero

6. Power factor is one for
(a) pure inductor
(b) pure capacitor
(c) pure resistor
(d) either an inductor or a capacitor.

7. Of the following about capacitive reactance which is correct
(a) the reactance of the capacitor is directly proportional to its ability to store charge
(b) capacitive reactance is inversely proportional to the frequency of the current
(c) capacitive reactance is mesured in farad
(d) the reactance of a capacitor in an A.C. circuit is similar to the resistance of a capacitor in a D.C. circuit

8. With increase in frequency of an A.C. supply, the inductive reactance
(a) decrease
(b) increases directly proportional to frequency
(c) increases as square of frequency
(d) decreases inversely with frequency

9. With increase in frequency of an A.C. supply, the impedance of an L-C-R series circuit
(a) remains constant
(b) increases
(c) decreases
(d) decreases at first, becomes minimum and then increases.

10. For long distance transmission, the ac is stepped up because of high voltage, the transmission is
(a) faster (b) economical
(c) undamped (d) less dangerous

11. The transformer voltage induced in the secondary coil of a transformer is mainly due to
(a) a varying electric field
(b) a varying magnetic field
(c) the vibrations of the primary coil
(d) the iron core of the transformer

12. Eddy currents in the core of transformer can't be developed
(a) by increasing the number of turns in secondary coil
(b) by taking laminated transformer
(c) by making step down transformer
(d) by using a weak a.c. at high potential

13. The frequency of A.C. mains in India is
(a) 30 c/s (b) 50 c/s
(c) 60 c/s (d) 120 c/s

14. Hot wire ammeters are used for measuring
(a) A.C. only (b) D.C. only
(c) both A.C. and D.C. (d) none of these

15. Alternating current cannot be measured by D.C. ammeter because
(a) A.C. cannot pass through D.C. ammeter
(b) average value of current for complete cycle is zero
(c) A.C. is virtual
(d) A.C. changes its direction

16. Alternating current is converted to direct current by
(a) rectifier (b) dynamo
(c) transformer (d) motor

17. A transformer is employed to
(a) convert A.C. into D.C.
(b) convert D.C. into A.C.
(c) obtain a suitable A.C. voltage
(d) obtain a suitable D.C. voltage

18. To convert mechanical energy into electrical energy, one can use
(a) DC dynamo (b) AC dynamo
(c) motor (d) (a) & (b)

19. The AC voltage across a resistance can be meausred using
(a) a potentiometer
(b) a hot-wire voltmeter
(c) a moving-coil galvanometer
(d) a moving-magnet galvanometer

20. A choke is preferred to a resistance for limiting current in A.C. circuit because
(a) choke is cheap
(b) there is no wastage of energy
(c) current becomes wattless
(d) current strength increases

21. A choke coil has
(a) high inductance and high resistance
(b) low inductance and low resistance
(c) high inductance and low resistance
(d) low inductance and high resistance

22. Transformers are used
(a) in DC circuit only
(b) in AC circuits only
(c) in both DC and AC circuits
(d) neither in DC nor in AC circuits

23. A rectangular coil of copper wires is rotated in a magnetic field. The direction of the induced current changes once in each
(a) two revolutions (b) one revolution
(c) half revolution (d) one-fourth revolution

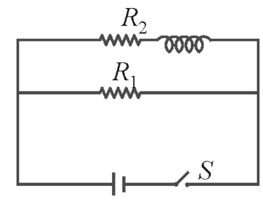
DIRECTIONS (Qs. 24-29): *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

24. The reactance of a circuit is zero. It is possible that the circuit contains
(a) an inductor and a capacitor
(b) an inductor but no capacitor
(c) a capacitor but no inductor
(d) neither an inductor nor a capacitor

25. In an AC series circuit, the instantaneous current is zero when the instantaneous voltage is maximum.Connected to the source may be a
(a) pure inductor
(b) pure capacitor
(c) pure resistor
(d) combination of an inductor and a capacitor

26. An inductor-coil having some resistance is connected to an AC source. Which of the following quantities have zero average value over a cycle?
(a) current
(b) induced e.m.f. in the inductor
(c) joule heat
(d) magnetic energy stored in the inductor

27. Figure shows a circuit with two resistors and an ideal inductor.



(a) The current in R_1 is zero just after closing the switch S.
(b) The current in R_1 is maximum just after closing the switch S.
(c) The current in R_2 is zero just after closing of the switch S.
(d) The currents in the resistors are maximum of their values a long time after closing the switch S.

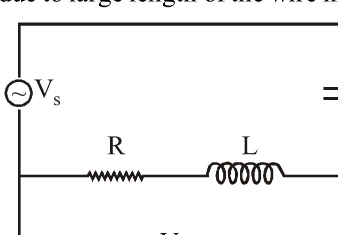
28. L, C and R represent inductance, capacitance and resistance respectively. Which of the following have dimensions of frequency ?
(a) $\frac{L}{C}$ (b) $\frac{1}{\sqrt{LC}}$
(d) $\frac{R}{L}$ (d) $\frac{1}{RC}$

29. If the inductance L in an oscillating LC circuit having a given maximum charge Q is increased, then
(a) the current magnitude increases
(b) the maximum magnetic energy increases
(c) the maximum magnetic energy decreases
(d) current magnitude and maximum magnetic energy remain constant.

DIRECTIONS (Qs. 30-37): *Study the given paragraph(s) and answer the following questions.*

Passsage I

One application of LRC series circuit is to high pass or low pass filters, which filter out either the low or high frequency components of a signal. A high pass filter is shown in figure, where the output voltage is taken across the LR combination, where LR combination represents an inductance coil that also has resistance due to large length of the wire in the coil.



30. Find the ratio for V_{out}/V_s as a function of the angular frequency ω of the source :

(a) $\sqrt{\dfrac{R^2+\omega L^2}{R^2+\left(\omega L-\dfrac{1}{\omega C}\right)^2}}$ (b) $\sqrt{\dfrac{R^2+(\omega L)^2}{R^2+\left(\omega L-\dfrac{1}{\omega C}\right)^2}}$

(c) $\sqrt{\dfrac{R^2+\omega^2 L}{R^2+\left(\omega L-\dfrac{1}{\omega C}\right)^2}}$ (d) 1

31. Which of the following statements is correct when ω is small, in the case of V_{out}/V_s?

(a) ωRC (b) $\dfrac{\omega R}{L}$

(c) ωRL (d) $\dfrac{\omega R}{C}$

32. Which statement is correct in the limit of large frequency is reached? (For V_{out}/V_s?)

(a) 1 (b) ωRC

(c) ωRL (d) $\dfrac{\omega R}{L}$

Passsage II

A fresh man physics lab is designed to study the transfer of electrical energy from one circuit to another by means of a magnetic field using simple transformers. Each transformer has two coils of wire electrically insulated from each other but wound around a common core of ferromagnetic material. The two wires are close together but do not touch each other. The primary coil is connected to a resistor such as a light bulb. The AC source produces an oscilating voltage and current int he primary coil that produces an oscillating magnetic field in the core material. This in turn induces an oscilating voltage and AC current in the secondary coil. Students collected the following data comparing the number of turns per coil (N), the voltage (V) and the current (I) in the coils of three transformeers.

	Primary Coil			Secondary Coil		
	N_1	V_1	I_1	N_2	V_2	I_2
Transformer 1	100	10V	10A	200	20V	5A
Transformer 2	100	10V	10A	50	5V	20A
Transformer 3	200	10V	10A	100	5V	20A

33. The primary coil of a transformer has 100 turns and is connected to a 120V AC source. How many turns are in the secondary coil if there is a 2400V across it?

(a) 5 (b) 50
(c) 200 (d) 2000

34. A transformer with 40 turns in its primary coil is connected to a 120 V AC source. If 20 watts of power is supplied to the primary coil, how much power is developed int eh secondary coil?

(a) 10 W (b) 20 W
(c) 80 W (d) 160 W

35. Which of the following is a correct expression for R, the resistance of the load connected to the secondary coil?

(a) $\left(\dfrac{V_1}{I_1}\right)\left(\dfrac{N_2}{N_1}\right)$ (b) $\left(\dfrac{V_1}{I_1}\right)\left(\dfrac{N_2}{N_1}\right)^2$

(c) $\left(\dfrac{V_1}{I_1}\right)\left(\dfrac{N_1}{N_2}\right)$ (d) $\left(\dfrac{V_1}{I_1}\right)\left(\dfrac{N_1}{N_2}\right)^2$

36. The primary coil of a given transformer has $\dfrac{1}{3}$ as many turns as in its secondary coil. What primary current is required to provide a secondary current of 3.0 mA?

(a) 1.0 mA (b) 6.0 mA
(c) 9.0 mA (d) 12.0 mA

37. A 12 V battery is used to supply 2.0 mA of current to the 300 turns in the primary coil of a given transformer. What is the current in the secondary coil if N_2 = 150 turns?

(a) 0A (b) 1.0 mA
(c) 2.0 mA (d) 4.0 A

DIRECTIONS (Qs. 38-42): *Each of these questions contains an Assertion followed by reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) **Assertion** is true, **Reason** is true; **Reason** is a correct explanation for **Assertion**
(b) **Assertion** is true, **Reason** is true; **Reason** is not a correct explanation for **Assertion**
(c) **Assertion** is true, **Reason** is false
(d) **Assertion** is false, **Reason** is true

38. **Assertion :** Alternating current does not show magnetic field.
Reason : Alternating current varies with time.

39. **Assertion :** A step up transformer can be used as a step down transformer.
Reason : This is because in a transformer, $\dfrac{E_s}{E_p}=\dfrac{n_s}{n_p}$.

40. **Assertion :** When number of turns in a coil is doubled, coefficient of self-inductance of the coil becomes 4 times.
Reason : This is because $L \propto N^2$.

41. **Assertion :** An induced current has a direction such that the magnetic field due to the current opposes the change in the magnetic flux that induces the current.
Reason : Above statement is in accordance with conservation of energy.

42. **Assertion :** The coil in the resistance boxes are made by doubling the wire.
Reason : Thick wire is required in resistance box.

DIRECTIONS (Q. 43) : *Following question has four statements (A, B, C and D) given in Column I and four statements (p, q, r and s) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

43. Column I gives some incomplete statements. Column II gives some completing statements. Match them correctly.

	Column I		Column II
(A)	A.C. changes periodically	(p)	$N_p > N_s$
(B)	Rate of transferring energy	(q)	$N_s > N_p$
(C)	Step-up transformer	(r)	Power
(D)	Step down transformer	(s)	magnitude
		(t)	direction

	A	B	C	D
(a)	s,r	r, p	q	q
(b)	s, t	r,	q	p
(c)	p, q	s	r, t	q
(d)	q, r	q, p	s	s,t

DIRECTIONS (Qs. 44-47) : *Following are integer based/ Numeric based questions. Each question, when worked out will result in one integer or numeric value.*

44. A 100 μF capacitor in series with a 40 Ω resistance is connected to a 110 V, 60 Hz supply.
(a) What is the maximum current in the circuit?
(b) What is the time lag between maximum current and maximum voltage?

45. A R-L circuit draws a power of 440W from a source of 220V, 50Hz. The power factor of the circuit is 0.5. To make the power factor of the circuit as 1.0, what capacitance will have to be connected with it ?

46. A variable frequency 230V alternating voltage source is connected across a series combination of L = 5.0H, C = 80μF and R = 40Ω. Calculate :
(a) The angular frequency of the source at resonance.
(b) Amplitude of current at resonance frequency.

47. A small town with a demand of 800 kW of electric power at 220 V is situated 15 km away from an electric power plant generating power at 440 V. The resistance of the two wire line carrying power is 0.5 Ω per km. The town gets from the line through a 4000 – 220 V step down transformer at a sub-station in the town.
(a) Estimate the line power loss in the form of heat.
(b) How much power must be plant supply, assuming there is a negligible power loss due to leakage?
(c) Characterise the step up transformer at the plant.

SOLUTIONS

Brief Explanations of Selected Questions

EXERCISE

1. (a) **2.** (c) **3.** (a) **4.** (b) **5.** (b) **6.** (c)
7. (b) **8.** (b) **9.** (d) **10.** (c) **11.** (b) **12.** (b)
13. (b) **14.** (c) **15.** (b) **16.** (a) **17.** (c) **18.** (d)
19. (b) **20.** (b) **21.** (c) **22.** (b) **23.** (c)
24. (a, d) **25.** (a, b, d) **26.** (a, b) **27.** (b, c, d)
28. (b, c, d) **29.** (a, b)
30. (b) **31.** (a) **32.** (a) **33.** (d) **34.** (c) **35.** (b)
36. (b) **37.** (a) **38.** (b) **39.** (d) **40.** (a) **41.** (b)
42. (c) **43.** (b)

44. (a) Here, $C = 100\ \mu F = 100 \times 10^{-6}\ F, R = 40\ \Omega$,
$V_{rms} = 110\ V, f = 60\ Hz$

Peak voltage, $V_0 = \sqrt{2}.V_{rms} = 110\sqrt{2} = 155.54\ V$

Circuit impedance,

$$Z = \sqrt{R^2 + \frac{1}{\omega^2 C^2}} = \sqrt{40^2 + \frac{1}{(2 \times \pi \times 60 \times 100 \times 10^{-6})^2}}$$

$$= \sqrt{1600 + 703.60} = \sqrt{2303.60} = 48\ \Omega$$

Hence, maximum current in coil,

$$I_0 = \frac{V_0}{Z} = \frac{155.54}{48} = 3.24\ A$$

(b) Phase lead angle (for current),

$$\theta = \tan^{-1} \frac{1}{\omega C R}$$

$$= \tan^{-1} \frac{1}{2 \times 3.14 \times 60 \times 100 \times 10^{-6} \times 40}$$

$$= \tan^{-1} 0.66315 = 33° 33' \text{ (taken } 33.5°)$$

Time lead,

$$t = \frac{\theta}{\omega} = \frac{\theta}{2\pi\nu} = \frac{33.5}{360 \times 60}$$

$$= 0.001551 \text{ sec} = 1.551 \times 10^{-3} \text{ sec}$$

Voltage will lag current by time 1.551 ms.

45. $\because$ Power $P = VI\cos\phi = \frac{V^2}{Z}\cos\phi$

$$\therefore Z = \frac{V^2 \cos\phi}{P} = \frac{(220)^2 (0.5)}{(440)} = 55\ \Omega$$

Also power factor

$$\cos\phi = \frac{R}{Z} \Rightarrow R = Z\cos\phi = (55)(0.5) = 27.5\ \Omega$$

$$\therefore X_L = \sqrt{Z^2 - R^2} = \sqrt{(55)^2 - \left(\frac{55}{2}\right)^2} = \frac{55\sqrt{3}}{2}\Omega$$

when power factor is 1.0 then $X_L = X_C$

$$\text{so } X_L = \frac{1}{\omega C} \Rightarrow C = \frac{1}{\omega X_L} = \frac{1}{(314)\left(\frac{55\sqrt{3}}{2}\right)} = 6.68 \times 10^{-5}\ F$$

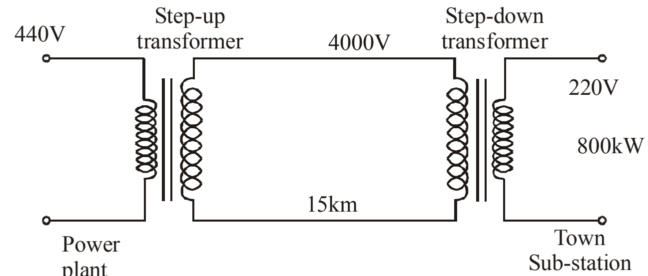
46. (a) Angular frequency at resonance

$$\omega_r = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{5.0 \times 80 \times 10^{-6}}} = \frac{10^2}{2} = 50 \text{ rad/s}$$

(b) Amplitude of current at resonance

$$I_m = \frac{V}{R} = \frac{230\sqrt{2}}{40} = 8.13\ A$$

47. The diagram shows the network :



For sub-station, $P = 800\ kW = 800 \times 10^3$ watt
$V = 220\ V$

$$I_S = \frac{P}{V} = \frac{800 \times 10^3}{220} = \frac{40}{11} \times 10^3\ A.$$

Primary current (I_p) in sub-station transformer will be given by $4000 \times I_P = 220 \times I_S$

$$I_P = \frac{220 \times 40 \times 10^3}{11 \times 4000} = 200\ A$$

(a) Hence transmission line current = 200 A
Transmission line resistance = $2 \times 15 \times 0.5 = 15\ \Omega$
Transmission line power loss
$= I^2R = 200 \times 200 \times 15 = 6 \times 10^5$ watt $= 600$ kW.

(b) Power to be supplied by plant = power required at substation + loss of power of transmission
$= 800 + 600 = 1400$ kW.

(c) Voltage in secondary at power plant has characteristics

$$= \frac{\text{Power}}{\text{Current}} = \frac{1400\ kW}{200\ A} = \frac{1400 \times 1000}{200} = 7000\ V$$

Step-up transformer at power plant has characteristics 440 - 7000 V.

Chapter 8

MODERN PHYSICS

INTRODUCTION

All matters are composed of what is called 'atom'. Atom is composed of fundamental particles electron, proton and neutron and it has a nucleus in which its mass i.e., no. of protons + no.of neutrons is concentrated.

The story of how atom was discovered is very long. But the brief story is that first of all Thomson provided something acceptable in scientific community about the atom. After him, Rutherford presented the modified and almost acceptable atomic model but it had also some discrepencies which was removed by Neils Bohr when he presented the most updated form of the atomic model in 1913.

This chapter provides us the structure of atom and its different features. The chapter also gives a glimpse of the nucleus and different phenomena occuring in it like radioactivity, fission, fusion etc.

You will also study the applications of these nuclear phenomena such as in atom bomb, hydrogen bomb, and so on.

THE ATOM

Observations and experiments have concluded that atom is the basic constituent of each substance; which is neutral and stable. In Vedas, references are given about the basic constituent of the substances. It is called atom. After the Rutherford experiments, it has been accepted that positive nucleus is the centre of the atom and electrons are revolving around the nucleus in different orbits. In last hundred years, scientists have discovered the following facts regarding the atom. These are :

(i) The atom as a whole is neutral.
(ii) The atom is stable.
(iii) The size of the atom is order of 10^{-10} m.
(iv) The atom emits discrete radiations etc.

THOMSON'S ATOMIC MODEL

This model suggests an atom to be a tiny sphere of radius $\approx 10^{-10}$ m, containing the positive charge. The atom is electrically neutral. It contains an equal negative charge in the form of electrons, which are embedded randomly in this sphere, like seeds in a watermelon.

This model failed to explain:

(i) Large scattering angle of α-particle

(ii) Origin of spectral lines observed in the spectrum of hydrogen atom.

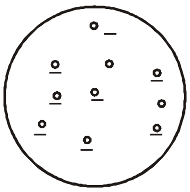


Fig 8.1 Thomson's atomic model

RUTHERFORD'S ATOMIC MODEL

(i) Atom is sphere of diameter about 10^{-10} m and central part called nucleus contains + ve charge protons most of the masses of atom.
(ii) The diameter of the nucleus is of the order of 10^{-15} m
(iii) The space around the nucleus is almost empty. It is filled only with tiny sized electrons which revolve around the nucleus in different orbits.
(iv) The electrostatic attraction between the nucleus and electron provides centripetal force required for circular motion.
(v) Total positive charge in the nucleus is equal to total negative charge at the atom.

Drawbacks of Rutherford Model

(i) The electron orbiting around the nucleus is under acceleration. So it must radiate energy. This may result in radius of orbits decreasing gradually.
(ii) According to the Rutherford, electron can revolve in all possible orbits hence the atom should emit radiation of all possible wave length. But in reality atoms are found to have line spectrum.

BOHR'S ATOMIC MODEL

In 1913 Bohr gave his atomic theory primarily to explain, the spectra of hydrogen and hydrogen-like atoms. His theory, contained a combination of views from Plank's quantum theory, Einstein's photon concept and Rutherford model of atom. The Bohr theory can explain, the atomic spectra of hydrogen atom and hydrogen-like ions such as He^+, Li^{2+}, Be^{3+}.......(one electron ions). But his theory failed to explain, the spectra of more complex atom and ions. The basic postulates of Bohr's model are

(i) The electron moves in circular orbits around the nucleus under the influence of coulombic force of attraction between the electron and the positively charged nucleus (as shown in figure below).

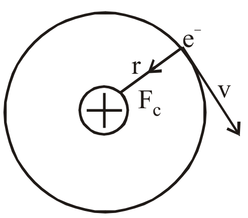


Fig. 8.2 Bohr's model of hydrogen atom

(ii) The electron rotates about the nucleus in certain stationary circular orbits, for which the angular momentum of electron about the nucleus is an integral multiple of $\frac{h}{2\pi} = \hbar$, where h is plank's constant i.e.,

$$mvr = \frac{nh}{2\pi} = n\hbar \text{ --- } (n = 1, 2, 3\text{......... where } n \text{ is principal quantum number}) \quad ...(1)$$

(iii) When the electron is in one of its stationary orbits, it does not radiate energy, hence the atom is stable.These stationary orbits are called allowed orbits.

(iv) The atom radiates energy when the electron "jumps" from one allowed stationary state to another. The frequency of radiation follows the condition $hv = E_i - E_f$ ...(2)

Where E_i and E_f are total energies of initial and final stationary states. This difference in energy $(E_i - E_f)$ between two allowed stationary states is radiated/absorbed in the form of a packet of electromagnetic energy (hv - one photon of frequency v) called **a photon**.

Radius and Energy of Hydrogen and Hydrogen Like Ions

Now, we calculate the allowed energies of hydrogen atom, by using the model shown in fig, in which the electron travels in a circular orbit of radius r with an orbital speed v.

For moving an electron in a circular orbit the required centripetal force is provided by the coulomb force of attraction which acts between nucleus [Ze^+, here $Z = 1$ (atomic number) for hydrogen atom] and electron (e^-),

i.e., $$\frac{mv^2}{r} = \frac{k\ e^2}{r^2} \quad ...(3)$$

where $k = \frac{1}{4\pi\varepsilon_o}$ is electrostatic constant and ε_0 is permittivity of free space.

Eliminating v from eq (1) & (3) we obtain

$$r \text{ (radius of } n\text{th state)} = \frac{n^2\hbar^2}{mke^2} = \frac{\varepsilon_o n^2 h^2}{\pi me^2} \quad (n = 1, 2, 3 \ldots\ldots\ldots\ldots) \quad ...(4)$$

Equation (4) gives the radii of various orbits (have discrete values).

The smallest radius (also called Bohr radius) corresponds to $n = 1$ is

$$r_0 = \frac{\hbar^2}{mke^2} \cong 0.529 A^o \quad ...(5)$$

$\Rightarrow$ $\boldsymbol{r = 0.529\ n^2}$ **Å** for hydrogen atom and $\boldsymbol{r = 0.529 \times \frac{n^2}{Z}}$ **Å** for hydrogen like ions.

From equations (4) and (1) we obtain, $v^2 = \frac{n^2\hbar^2}{m^2r^2} = \frac{k^2e^4}{n^2\hbar^2} \Rightarrow v = \frac{ke^2}{n\hbar}$

or $$v = \frac{e^2}{2\varepsilon_o nh} = \left(\frac{c}{137}\right) \times \frac{1}{n} \quad \text{(For hydrogen atom)} \quad ...(6)$$

(velocity in nth state)

$v = \left(\frac{c}{137}\right)\frac{Z}{n}$ for hydrogen like ions $\frac{c}{137} = 2.19 \times 10^6\ ms^{-1}$

The total energy of electron is given by

$$E = K.E. + P.E. = \text{Kinetic energy} + \text{Potential energy} = \frac{1}{2}mv^2 + \frac{ke(-e)}{r}$$

$$E \text{ (allowed energy state)} = \frac{-ke^2}{2r} = \frac{-me^4}{8\varepsilon_o n^2 h^2} \quad ...(7)$$

After substituting numerical values in Eq.(7), we obtain

$$\boldsymbol{E = \frac{-13.6}{n^2} eV} \quad \text{(For hydrogen atom)} \quad ...(8)$$

$E = \frac{-13.6Z^2}{n^2}\ eV/\text{atom}$ for hydrogen like ions.

The lowest energy state, or ground state, corresponds to $n = 1$ is $E_0 = \frac{-me^4}{8\varepsilon_o h^2} = -13.6eV$

The next state corresponds to $n = 2$ i.e., first excited state has an energy, $E = -\frac{13.6\text{ev}}{\text{n}^2} = -\frac{13.6ev}{4} = -3.4\ eV$

Limitations of Bohr's Model

(i) It could not explain the spectra of atoms containing more than one electron.
(ii) There was no theoretical basis for selecting mvr to be an integral multiple of $h/2\pi$.
(iii) It involved the orbit concept which could not be checked experimentally.
(iv) It could not explain Zeeman and Stark effect and fine lines of spectra.
(v) It was against De-broglie concept and uncertainty principle

Knowledge ENHANCER

If Bohr's quantization postulate (angular momentum = $nh/2\pi$) is a basic law of nature, it should be equally valid for the case of planetary motion also. Why then do we never speak of quantization of orbits of planets around the sun?

Angular momentum $mvr = n\dfrac{h}{2\pi}$ associated with planetary motion are incomparably large relative to h. For example angular momentum of Earth in its orbital motion is of the order of $10^{70}\dfrac{h}{2\pi}$.
For such large value of n, the difference in successive energies and angular momenta of the quantised levels of the Bohr model are so small that one can predict the energy level continuous.

ENERGY LEVEL DIAGRAM FOR HYDROGEN ATOM

Some transitions for Lyman, Balmer and Paschen series are shown.
The quantum numbers are at left and energies of levels are at right.
In this case ......$E = 0$ for $r = \infty$ (because $n = \infty$)
If the electron jumps from allowed state n_i to allowed state n_f, then frequency of emitted photon is given by

$$\nu = \frac{E_f - E_i}{h} = \frac{me^4}{8\varepsilon_o h^3}\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right) \quad ...(i)$$

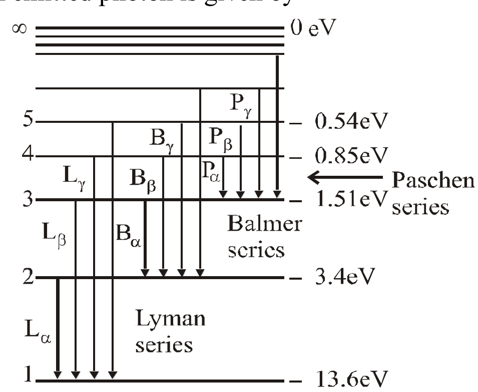


Fig 8.3 Energy level diagram for hydrogen atom

and the wavelength of emitted photon is $\dfrac{1}{\lambda} = \dfrac{\nu}{c} = \dfrac{me^4}{8\varepsilon_o ch^3}\left(\dfrac{1}{n_i^2} - \dfrac{1}{n_f^2}\right)$ ...(ii)

$$\frac{1}{\lambda} = R\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right) \text{ for hydrogen atom}$$

and $\bar{\nu} = \dfrac{1}{\lambda} = RZ^2\left[\dfrac{1}{n_1^{\,2}} - \dfrac{1}{n_2^{\,2}}\right]$ (for H-like atoms)

where $R = 1.096776 \times 10^7 \text{m}^{-1}$ is known as Rydberg constant. By using this expression (i.e., equation ii) we can calculate the wavelengths for various series (Lyman, Balmer...) in hydrogen spectrum, i.e.

(i) Lyman series $n_i = 1$ & $n_f = 2, 3, 4$...............
(ii) Balmer series $n_i = 2$, & $n_f = 3, 4, 5$...............
(iii) Paschen series $n_i = 3$ & $n_f = 4, 5, 6$.............
(iv) Brackett series $n_i = 4$ & $n_f = 5, 6, 7$...............
(v) P fund series $n_i = 5$ & $n_f = 6, 7, 8$...............

In practice, the value of Rydberg constant varies between $\dfrac{R}{2}$ and R

This is because in above calculations we assumed that electron revolves around a massive fixed nucleus of mass M. But in reality, the electron & nucleus each revolve round their common center of mass i.e., the motion of nucleus cannot be ignored. The correction for nuclear motion amounts to replacing electronic mass m by reduced mass μ which is defined as

Reduced mass, $$\mu = \frac{\text{mM}}{\text{m} + \text{M}} \quad ...(iii)$$

So total energy by taking this correction is

$$E = \frac{-\mu\, e^4}{8\varepsilon_o h^2 n^2} \quad ...(iv)$$

If we are dealing with hydrogen like ions such as – He^+, Li^{2+}, Be^{3+}, Be^{4+} (one electron ions), each can be considered as a system of two charges, the electron of mass m & charge $-e$ & nucleus of mass M & charge +Ze, where Z is atomic number. The radii of circular orbits for these one electron ions can be written as

$$r = \frac{\varepsilon_o n^2 h^2}{\pi \mu Z e^2} = \frac{n^2 \hbar^2}{\mu k Z e^2} \; (n = 1, 2, 3............) \qquad ...(v)$$

and the allowed energies are given by $E \cong \dfrac{-\mu Z^2 e^4}{8 \varepsilon_o h^2 n^2} \; (n = 1, 2, 3.........)$ ...(vi)

WAVELENGTH LIMITS IN VARIOUS SPECTRAL SERIES OF HYDROGEN ATOM

(i) For Lyman series (in ultraviolet region)

$\lambda_{max} = 1216$ Å, $\lambda_{min} = 912$ Å here $n_i = 1$, $n_f = 2, 3$..............

(ii) For Balmer Series (in visible region)

$\lambda_{max} = 6563$ Å and $\lambda_{min} = 3646$ Å here $n_i = 2$, $n_f = 3, 4, 5$..............

(iii) For Paschen series (in infrared region)

$\lambda_{max} = 18751$ Å and $\lambda_{min} = 8107$ Å here $n_i = 3$, $n_f = 4, 5, 6$..............

(iv) For Brackett series (in infrared region)

$\lambda_{max} = 40477$ Å and $\lambda_{min} = 14572$ Å here $n_i = 4$, $n_f = 5, 6, 7$..............

(v) For p-fund series (in infrared region)

$\lambda_{max} = 74515$ Å and $\lambda_{min} = 22768$ Å here $n_i = 5$, $n_f = 6, 7, 8$..............

Keep in Memory

1. Energy of electrons in different orbits in an atom varies inversely with the square of the number of orbits. So, energy of electrons increases (decreases in negative) as the orbit becomes higher.
2. If energy of a particular orbit is E for H-atom then its value for a H-like atom with atomic number Z is given by $E' = E \times Z^2$.
3. If the radius of a particular orbit of H-atom is R then its value for a H-like atom is given by $R' = \dfrac{R}{Z}$.
4. If velocity of an electron in a particular orbit of H-atom be v then its value for a H-like atom is given by $v' = v \times Z$.
5. The time period of the electron in an orbit $T^2 \propto r^3$
6. Maximum number of spectral lines that can be emitted when an electron jumps from n^{th} orbit is $\dfrac{n(n-1)}{2}$
7. The first line of Lyman series is when electron jumps from $2 \to 1$, it is also called α-line
   The second line of lyman series is when electron jumps from $3 \to 1$, it is also called β–line
   depend on the area of cross-section of the wire used?

Knowledge ENHANCER

An electron drops from the fourth energy level in an atom to the third level and then to the first level. Two frequencies of light are emitted. How does their combined energy compare with the energy of the single frequency that would have been emitted if the electron had dropped from the fourth level directly to the first level?

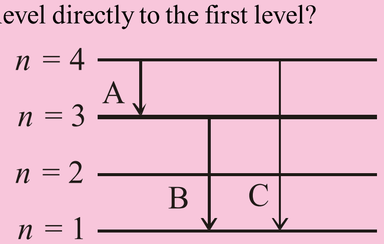


Fig. 8.4

In this figure we have shown the drop of an electron from fourth energy level ($n = 4$) to third energy level ($n = 3$) and during this transition it emits photons of frequency A. In another transition from third energy level ($n = 3$) to first energy level ($n = 1$), it emits photons of frequency B. In case the electron drops from fourth level to first level, it emits photons of frequency C. From the above diagram we can easily see that the sum of frequencies (and energies) for transitions A and B equals the frequency (and energy) of transition C. Energy of transition C = energy of transition A + energy of transition B

ILLUSTRATION : 8.1

Ionization potential of hydrogen atom is 13.6 eV. Hydrogen atom in the ground state are excited by monochromatic radiation of photon energy 12.1 *eV*. Which spectral lines will be emitted by hydrogen atoms according to Bohr's theory?

SOLUTION :

Given that $(\text{I.E.})_H = 13.6\, eV$ $\therefore$ $(E_1)_H = -(\text{I.E.})_H = -13.6\, eV$.

After absorbing 12.1 eV energy, the energy becomes

$-13.6\, eV + 12.1\, eV = -1.5\, eV$.

This energy corresponds to $n = 3$ level i.e., hydrogen atoms are excited to $n = 3$ level.

Now following three transitions are possible

$n = 3$ to $n = 1$, $n = 3$ to $n = 2$, and $n = 2$ to $n = 1$.

ILLUSTRATION : 8.2

The ionisation energy of Hydrogen atom is 13.6 eV. Following Bohr's theory, what is the energy corresponding to a transition between the 3rd and the 4th orbit?

SOLUTION :

As we know, energy corresponding to nth orbit,

$E_n = 13.6/n^2$

$E_3 = -(13.9/9) = -1.51\, eV$ and $E_4 = -(13.6/16) = -0.85\, eV$

Now $E_4 - E_3 = -0.85 - (-1.51) = 0.66\, eV$

ILLUSTRATION : 8.3

If the wavelength of the first line of the Lyman series for the hydrogen atom is 1210 Å, then what is the wavelength of the first line of the Balmer series of the hydrogen spectrum ?

SOLUTION :

We know that, $\dfrac{1}{\lambda} = R\left[\dfrac{1}{n_1^2} - \dfrac{1}{n_2^2}\right]$

For first line of Lyman series, $n_1 = 1$ and $n_2 = 2$

$$\therefore \quad \frac{1}{\lambda_1} = R\left[\frac{1}{1} - \frac{1}{4}\right] = \frac{3R}{4} \text{ or } R = \frac{4}{3\lambda_1}$$

For first line of Balmer series $n_1 = 2$ and $n_2 = 3$

$$\therefore \quad \frac{1}{\lambda_2} = R\left[\frac{1}{4} - \frac{1}{9}\right] = \frac{5R}{36} = \frac{5}{36}\left[\frac{4}{3\lambda_1}\right]$$

$$\text{or, } \frac{1}{\lambda_2} = \frac{5}{36} \times \frac{4}{3} \times \frac{1}{1210} \qquad \text{or, } \lambda_2 = \frac{36 \times 3 \times 1210}{5 \times 4} = 6434\, Å$$

ILLUSTRATION : 8.4

If the electron in hydrogen atom jumps from the third orbit to second orbit, what is the wavelength of the emitted radiation?

SOLUTION :

$$\frac{1}{\lambda} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] \text{ or } \frac{1}{\lambda} = R\left[\frac{1}{4} - \frac{1}{9}\right] = \frac{5R}{36} \qquad \therefore \quad \lambda = \frac{36}{5R}$$

CATHODE RAY AND ITS PROPERTIES

Discharge Tube Experiment

- When a very strong potential difference is applied across the two electrodes in a discharge tube and the pressure of the air is lowered gradually, then a stage is reached at which the current begins to flow through the air with cracking noise. The potential at which this happens is called **sparking potential**.

- As pressure is lowered to 0.1 m.m. Hg – cathode glow, Crooke's dark space, negative glow, Faraday dark space and striations are observed.

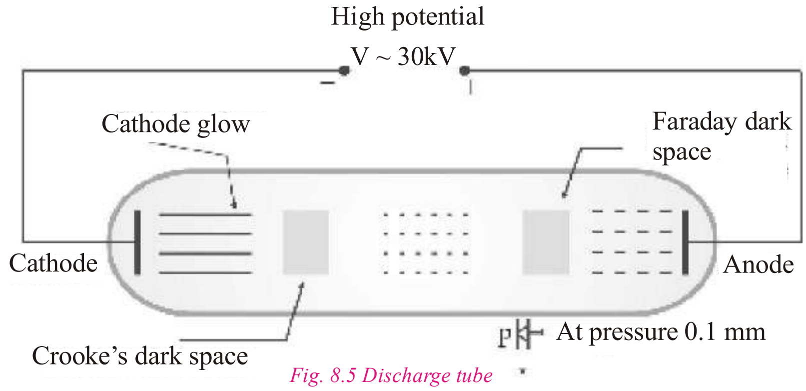


Fig. 8.5 Discharge tube

- At pressure 0.01 m.m. Hg entire tube is dark (Crooke's dark space) except the glass wall behind anode. Colour is yellowish-green for soda glass and greyish-blue for lead glass.
- The luminous streaks travelling from cathode to anode, below 0.01 m.m. Hg, are called **cathode rays.**

Properties of Cathode Rays

(i) Emitted perpendicularly to cathode (ii) Travel in straight lines (iii) Carry energy (iv) Possess momentum (v) Deflected by electric and magnetic fields (vi) Excite fluroescence (vii) Ionise gas (viii) Produce highly penetrating secondary radiation when suddenly stopped (ix) Effect photographic plate.

Positive Rays

Stream of +ve ions moving towards cathode in discharge tube.

Properties of positive rays

(i) Rays are made up of positively charged particles.
(ii) Being heavy, their velocity is much less than that of cathode rays.
(iii) They ionise the gas through which they pass and ionising power of positive rays is more than that of cathode rays.
(iv) Positive rays are deflected by electric and magnetic field showing that they carry +ve charge with them.

PHOTOELECTRIC EFFECT

In 19^{th} century, experiments showed that when light is incident on certain metallic surfaces, electrons are emitted from the surfaces. This phenomenon is known as the **photo-electric effect** and emitted electrons are called **photoelectrons.** The first discovery of this phenomenon was made by Hertz.
Figure shows, when light strikes the cathode C, electrons are emitted and they are collected on anode A due to potential difference provided by battery and constitutes the current in the circuit (observed by Galvanometer G.)

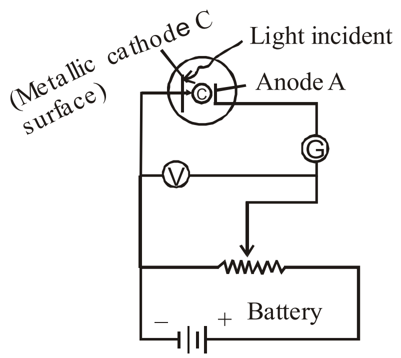


Fig. 8.6 When light strikes the cathode C (metallic surface), photoelectrons are ejected. Electrons are collected at anode A, constituting a current in the circuit. (Photoelectric effect)

A plot of photoelectric current versus the potential difference V between cathode and anode is shown in figure below.

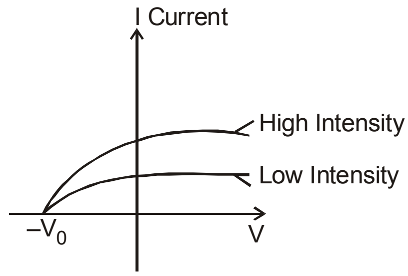


Fig. 8.7 Photoelectric current versus voltage for two light intensities. The current increases with intensity, but reaches a saturation. At voltage less than $-V_0$ the current is zero.

It is clear from figure that photoelectric current increases as we increase the intensity of light and obtain saturation value at larger value of potential difference V between cathode and anode. If V is negative then, photoelectrons are repelled by negative anode and only those electrons reaches anode, who have energy equal to or greater than eV. But if V is equal to V_0, called stopping potential (i.e., cut off. potential), no electrons will reach the anode i.e.,

Maximum Kinetic energy of electron = eV_0

or $K_{max} = eV_0$ ...(1)

where e is charge of electron (i.e. 1.6×10^{-19} coulomb).

But some features of photoelectric effect cannot be explained by classical physics and the wave theory of light.

(1) No photoelectrons are emitted, if the frequency of incident light is less than some cut-off frequency (i.e., threshold frequency) ν_0. It is inconsistent with the wave theory of light, which predicts that photoelectric effect occurs at any frequency provided intensity of incident light is sufficiently high.

(2) The maximum kinetic energy of the photo electrons is independent of light intensiy, but increases with increasing the frequency of incident light.

(3) Electrons are emitted from surface almost instantaneously (less than 10^{-9} sec after the surface illumination), even at low intensity of incident light(classicaly we assume that the electrons would require some time to absorb the incident light before they acquire enough kinetic energy to escape from metal).

These above points were explained by Einstein in 1905 by treating the light as stream of particles. Taking Max Planck's assumption, Einstein postulated that a beam of light consists of small packets of energy called photons or quanta. The energy E of a photon is equal to a constant h times its frequency ν

i.e., $E = h\nu = \dfrac{hc}{\lambda}$ ....(2)

Where h is a universal constant called Planck's constant and numerical value of $h = 6.62607 \times 10^{-34}$ J.s

When a photon arrives at surface, it is absorbed by an electron. This energy transfer is an All-or-Nothing process, in contrast to continuous transfer of energy in classical theory; the electrons get all photon's energy or none at all. If this energy is greater than the work function ϕ of the metal (ϕ i.e., work function is the minimum energy required to remove the electron from metal surface), the electron may escape from the surface. Greater intensity at a particular frequency means greater number of photons per second absorbed and consequently greater number of electrons emitted per second and so greater current.

To obtain maximum kinetic energy $K_{max} = \frac{1}{2}mv_{max}^2$ for an emitted electron, appling conservation of energy. According to it

$$K_{max} = \frac{1}{2}mv_{max}^2 = h\nu - \phi$$

$$K_{max} = h(\nu - \nu_0) \quad ...(3)$$

or $$eV_0 = K_{max} = h(\nu - \nu_0) \quad ...(4)$$

Where V_0 = cut-off potential

v_{max} = maximum velocity obtained by photoelectrons

ν = frequency of incident light i.e., photon

ν_0 = cut off frequency or threshold frequency.

ν_0 is different for different metallic surfaces. For most metals the threshold frequency is in ultarviolet region of spectrum. (Corresponding to l between 200 and 300 nm), but for potassium and cesium oxides, it is in the visible spectrum (λ between 400 and 700 nm).

WORK FUNCTIONS OF SOME ELEMENTS

Every metal has a definite work function. Why do all photoelectrons not come out with the same energy if incident radiation is monochromatic? Why is there an energy distribution of photoelectrons?

By work function of a metal, we mean the minimum energy required for the electron in the highest level of conduction band to get out of the metal. Since all the electrons in the metal do not belong to that level but they occupy a continuous band of levels, therefore, for the given incident radiation, electrons knocked off from different levels come out with different energies.

Element	(Work function) (eV)
Al (Aluminium) (4.3)	Ni (Nickel) (5.1)
C (Carbon) (5.0)	Si (Silicon) (4.8)
Cu (Copper) (4.7)	Ag (Silver) (4.3)
Au (Gold) (5.1)	Na (Sodium) (2.7)

Where 1 eV = 1.602×10^{-19} joule.

Within the frame work of photon theory of light (Quantum theory of light) we can explain above failures of classical physics.

(1) It is clear from eq. (3) that if energy of photon is less than the work function of metallic surface, the electrons will never be ejected from surface regardless of intensity of incident light.

(2) K_{max} is independent of intensity of incident light, but it depends on the frequency of incident light [i.e., $K_{max} \propto \nu$ (frequency of light)].

(3) Electrons are emitted almost instantaneously consistent with particle view of light in which incident energy is concentrated in small packets (called photons) rather than over a large area (as in wave theory).

ILLUSTRATION : 8.5

The work function of cesium is 1.8 eV. Light of 5000 Å is incident on it. Calculate (a) threshold frequency and threshold wavelength. (b) maximum K.E. of emitted electrons. (c) maximum velocity of emitted electrons (d) if the intensity of the incident light be doubled, then what will be the maximum K.E. of the emitted electrons? ($h = 6.6 \times 10^{-34}$ joule second, mass of electron $m = 9.0 \times 10^{-31}$ kg and speed of light $c = 3 \times 10^8$ m/s).

SOLUTION :

(a) As we know, $W_0 = h\nu_0$ or $\nu_0 = h / W_0$

$$W_0 = 1.8 \times (1.6 \times 10^{-19}) = 2.9 \times 10^{-19} \text{ joule}$$

$$\therefore \text{Threshold frequency, } \nu_0 = \frac{W_0}{h} = \frac{2.9 \times 10^{-19} \text{ joule}}{6.6 \times 10^{-34} \text{ joule second}} = 4.4 \times 10^{14} \text{ sec}^{-1}$$

$$\text{Threshold wavelength } \lambda_0 = \frac{c}{\nu_0} = \frac{3.0 \times 10^8 \text{ m/s}}{4.4 \times 10^{14} \, s^{-1}} = 6.8 \times 10^{-7} \text{ metre} = 6800 \text{ Å}$$

(b) Maximum kinetic energy. $E_k = h\nu - W_0 = \dfrac{hc}{\lambda} - W_0$

$$= \frac{(6.63 \times 10^{-34})(3 \times 10^8)}{5000 \times 10^{-10}} - (2.9 \times 10^{-19} \text{ joule}) = (4.0 - 2.9) \times 10^{-19} = 1.1 \times 10^{-19} \text{ joule.}$$

(c) $\because E_k = \dfrac{1}{2} m v_{max}^2$

$$\therefore v_{max} = \sqrt{\left(\frac{2E_k}{m}\right)} = \sqrt{\left[\frac{2 \times (1.1 \times 10^{-19})}{9.0 \times 10^{-31}}\right]} = 5.0 \times 10^5 \text{ m/sec.}$$

(d) The K.E. of emitted electrons does not depend upon the intensity of light. Hence if the intensity of incident light be doubled, the energy will remain unchanged.

X-RAYS

The X-rays were discovered by Prof. Roentgen, a German scientist in 1885. He was awarded Nobel Prize for this discovery in 1901. The modern apparatus for the production of X-rays was developed by Dr. Coolidge in 1913.

Production of X-rays

X-rays are produced when fast moving cathode rays are stopped suddenly by a metal called target.

The modern device used in the production of X-ray is called the Coolidge tube, which consists of a highly evacuated glass tube as shown in the figure.

A filament F emits electrons when it is heated by passing a low current through it. It also acts as a cathode. It is surrounded by a molybdenum cylinder M. The cylinder M focusses the electrons on a fine beam. The target is tungesten which is embedded in copper anode A. The anode A is inclined at 45º to the horizontal. It is cooled by circulating water around it. To produce X-rays, high speed electrons are required. For this, the electrons emitted from the filament are accelerated by applying a high potential difference between the anode and the cathode.

The fast moving electrons produce X-rays when they strike the target.

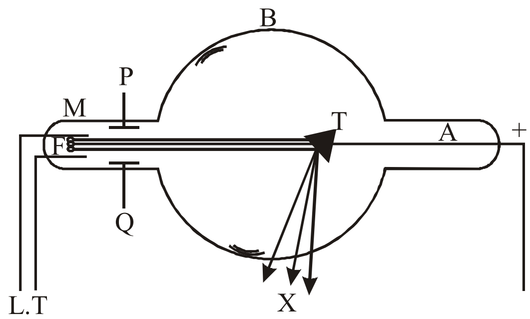


Fig. 8.8 Coolidge tube

Applications of x-rays

X-rays have important and useful applications in surgery, medicine, engineering and studies of crystal structures.

1. **Scientific applications:** The diffraction of X-rays at crystals opened a new dimension to X-rays crystallography. Various diffraction patterns are used for determining internal structure of crystals. The spacing and dispositions of atoms of a crystal can be precisely determined using Bragg's law : $n\lambda = 2d\sin\theta$.
2. **Industrial applications:** Since X-rays can penetrate through various materials, they are used in industry to detect defects in metallic structures in big machines, railway tracks and bridges. X-rays are used to analyse the composition of alloys and pearls.
3. **In radio therapy:** X-rays can cause damage to the tissues of body (cells are ionized and molecules are broken). So X-ray damages the malignant growths like cancer and tumors which are dangerous to life, when it used in proper and controlled intensities.
4. **In medicine and surgery:** X-rays are absorbed more in heavy elements than in lighter ones. Since bones (containing calcium and phosphorus) absorb more X-rays than the surrounding tissues (containing light elements like H, C, O), their shadow is casted on the photographic plate. So the cracks or Fractures in bones can be easily located. Similarly intestine and digestive system abnormalities are also detected by X-rays.

ATOMIC NUCLEUS

Rutherford proposed the existence of a nucleus in 1911 to explain the results of his α particle scattering experiment.

It is the central core of an atom in which the entire positive charge and neutron i.e., almost the entire mass of an atom is concentrated. All nuclei except hydrogen are made up of neutrons and protons. Hydrogen nucleus contains a single proton.

A nuclide is a specific nucleus of an atom characterized as ${}_{Z}X_{N}^{A}$ where A is mass number, Z is proton number and N is neutron number of an elements.

Proton : It is a charged particle carrying unit positive charge. Mass of proton $m_p = 1.6726 \times 10^{-27}$ kg = 1.007825 amu. It was discovered by Goldstein in 1919. The number of protons present inside the nucleus of an atom is called atomic number (Z) of an element. As atom is electrically neutral so number of protons inside the nucleus is equal to number of electrons (negatively charged particles) in an atom.

In lighter nuclei the number of neutrons and protons are equal while in heavier nuclei number of neutrons is greater than number of protons.

Neutron : It is a neutral particle carrying no charge. Mass of neutron $m_n = 1.6749 \times 10^{-27}$ kg = 1.008665 amu

They are not deflected by external electric and magnetic fields, have high penetrating power and low ionizing power are stable inside the nucleus. Outside the nucleus they are unstable with a half life of about 13 minutes.

Neutron was discovered by James Chadwick in 1932 when he tried to explain results of collision of α particles with Berrylium.

${}_{2}Be^{4} + {}_{2}He^{4} \longrightarrow {}_{6}C^{13} \longrightarrow {}_{6}C^{12} + {}_{0}n^{1} + Q$.

Size of Nucleus

Rutherford in his α particle scattering experiment calculated the distance of closest approach at which α particle approaching nucleus is turned around by Coulomb repulsion.

When α particle is turned, the kinetic energy must be converted to electric potential energy since collision is elastic.

$$\frac{1}{2}mv^2 = \frac{K(2e)\ (Ze)}{d}\ ;\ \text{Distance of closest approach}\quad d = \frac{4K\ Ze^2}{mv^2}$$

For gold, $Z = 79$, $\frac{1}{2}mv^2 = 7\text{MeV} = 7\times 1.6\times 10^{-13}\,\text{J}$

So, $d = \dfrac{2\times 9\times 10^9\times 79\times(1.6\times 10^{-19})^2}{7\times 1.6\times 10^{-13}} = 3.2\times 10^{-14}\,\text{m}$

He assumed the distance of closest approach as a measure of size of nucleus.

Radius of nucleus (R) is related to mass number (A) as $\boldsymbol{R = R_0A^{1/3}}$ where R_0 is constant and $R_0 = 1.25\times 10^{-15}$m

Density of Nucleus

Volume of nucleus $V = \frac{4}{3}\pi R^3 = \frac{4}{3}\pi R_0^3 A$ so, volume $V \propto A$

Mass of nucleus = mass of protons + mass of neutrons = mA where m is mass of one nucleon

Density of nucleus $\rho = \dfrac{\text{mass of nucleus}}{\text{volume of nucleus}} = \dfrac{mA}{\frac{4}{3}\pi R_0^3 A} = \dfrac{3m}{4\pi R_0^3}$

The *nuclear density is independent of mass number A*. The nuclear density is nearly constant and is equal to

$$\rho = \frac{3m}{4\pi R_0^3} = \frac{3\times 1.67\times 10^{-27}}{4\times 3.14\times(1.25\times 10^{-15})^3} = 1.8\times 10^{17}\,\text{kg/m}^3$$

The distance from the centre of nucleus where density becomes 50% of its density at centre is called nuclear radius. The high density of nucleus indicates compactness of nucleus.

Atomic mass unit : 1 atomic mass unit (amu) = $\frac{1}{12}$ of mass of carbon ($_6C^{12}$) atom

$$1\ \text{amu} = \frac{1}{12}\left(\frac{12}{6.023\times 10^{23}}\right) = 1.66\times 10^{-24}\,\text{g} = 1.66\times 10^{-27}\,\text{kg}$$

Energy equivalent to 1 amu mass : According to Einstein's mass energy equivalence relation

$E = mc^2 = 1.66\times 10^{-27}(3\times 10^8)^2$ joule $= 1.49\times 10^{-10}$ joule $= 931.5$ MeV, [1 amu $= 1.49\times 10^{-10}$ J $= 931.5$ MeV]

Nuclear Forces

The strong forces of attraction which firmly hold the nucleons in the small nucleus and account for stability of nucleus are called as nuclear forces.

The nuclear force is a short range force and is strongest force in nature. They are charge independent.

Force between a pair of protons, a pair of neutrons and a pair of neutron (n) and proton (P) is equal.

F(n — n) = F (p — p) = F (n — p)

The net force between pair of neutrons and a pair of neutron and proton is equal. This is slightly greater than force between pair of protons because force between protons is reduced due to electrostatic repulsion.

Net force F (n — n) = net force F(n — p) > net force F (p — p)

They are non-central forces i.e., they do not act along line joining the centre of two nucleons.

The nuclear forces originate by exchange of mesons (π^+, π°, π^-) between the nucleons.

Mass Defect

The mass of the nucleus is always less than the sum of masses of nucleons composing the nucleus.

The *difference between the rest mass of nucleus and sum of rest masses of nucleons constituting the nucleus is known as mass defect.* Mass defect $\Delta m = [Zm_P + (A-Z)m_n] - M(_ZX^A)$

BINDING ENERGY

The energy required to break a nucleus into its constituent nucleons and place them at infinite distance is called binding energy. The energy equivalent to mass defect is called binding energy. This is the energy with which the nucleons are held together.

The binding energies (~MeV) are very large as compared to molecular binding energies (~eV)

Binding energy $BE = (\Delta m)c^2 = c^2\,[Zm_P + (A-Z)m_n - M(_ZX^A)]$

Rest mass of protons + rest mass of neutrons = rest mass of nucleus + BE.

The *binding energy per nucleon of a nucleus is the average energy required to extract a nucleon from the nucleus.*

Binding energy per nucleon $\bar{B} = \dfrac{\text{Total binding energy}}{\text{Total number of nucleons}} = \dfrac{BE}{A} = \dfrac{\Delta mc^2}{A}$

$$= \frac{c^2}{A}[Zm_p + (A-Z)m_n - M(_ZX^A)]$$

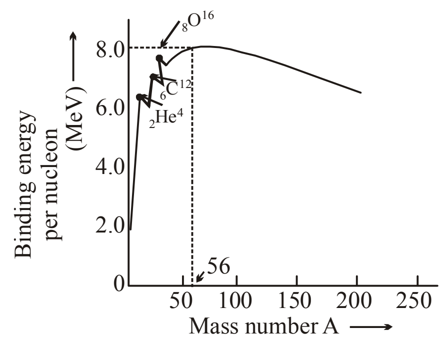


Fig. 8.9

The plot of binding energy per nucleon with mass number A is shown.
Binding energy per nucleon gives a measure of stability of nucleus.
More is binding energy per nucleon more is the stability of nucleus.
It is small for lighter nuclei i.e. $_1H^1$, $_1H^2$ etc.
For $A < 28$ at $A = 4n$ the curve shows some peaks at

$_2He^4$, $_4Be^8$, $_6C^{12}$, $_8O^{16}$, $_{10}Ne^{20}$, $_{12}Mg^{24}$.

This represents extra stability of these elements with respect to their neighbours .
It is almost constant about 8.5 MeV in range $40 < A < 120$. It is maximum about 8.8 MeV for Fe^{56}.
It decreases for $A > 200$. They become less stable and exhibit radioactivity.

Illustration 8.6

A nucleus breaks into two parts whose velocity is in the ratio of 2:1 . Find the ratio of their radii.

SOLUTION

As per conservation of momentum $m_1v_1 + m_2v_2 = 0$ so, $\dfrac{m_1}{m_2} = \dfrac{v_2}{v_1}$

Ratio of radii $\dfrac{R_1}{R_2} = \left(\dfrac{A_1}{A_2}\right)^{1/3} = \left(\dfrac{m_1}{m_2}\right)^{1/3} = \left(\dfrac{1}{2}\right)^{1/3}$ or, $R_1 : R_2 = 1 : 2^{1/3}$

Illustration 8.7

Calculate the binding energy per nucleon for $_{17}C^{35}$. Given M (Cl^{35}) = 34.9800 amu m_n = 1.008665 amu and m_P = 1.007825 amu.

SOLUTION

Binding energy $BE = Zm_P + (A-Z)\,m_n - M\,(Cl^{35}) = 17 \times 1.007825 + 18 \times 1.008665 - 34.9800 = 0.308995$ amu
$BE = 0.308995 \times 931.5 = 287.83$ MeV

Binding energy per nucleon, $\bar{B} = \dfrac{BE}{A} = \dfrac{287.75}{35} = 8.22$ MeV/nucleon

Illustration 8.8

Calculate the mass defect of a deutron ($_1H^2$). Given M($_1H^2$) = 2.014102 amu, m_n = 1.008665 amu, m_p = 1.007825 amu.

SOLUTION

Mass defect, $\Delta m = [Zm_P + (A-Z)m_n] - M(_1H^2)$
$= (1 \times 1.007825 + (2-1)\ 1.008665) - 2.014102$
$\Delta m = 0.002388$ amu

TYPES OF NUCLEI

Isotopes : These are nuclei of same element having same atomic number Z but different mass number A

e.g. $_8O^{16}$, $_8O^{17}$, $_8O^{18}$; $_1H^1$, $_1H^2$, $_1H^3$; $_{92}U^{234}$, $_{92}U^{235}$, $_{92}U^{238}$

All isotopes of an element have same chemical properties. They occupy same place in periodic table. They cannot be separated by chemical analysis. They can be separated by mass spectrometers or mass spectrographs.

Isotones : These are nuclei of different elements having same no. of neutrons N but different A.

e.g . $_6C^{13}_7$ & $_7N^{14}_7$; $_1H^3_2$ & $_2He^4_2$; $_2Be^9_5$ & $_5B^{10}_5$

Isotones are different elements with different chemical properties. They occupy different positions in periodic table. They can be separated by chemical analysis and mass spectrometers.

Isobars : These are nuclei of different elements having same A but different N and Z.

e.g $_6C^{14}$ and $_7N^{14}$; $_{18}Ar^{40}$ and $_{20}Ca^{40}$

Isobars are different elements with different chemical properties. They occupy different positions in periodic table. They can be separated by chemical analysis but cannot be separated by mass spectrometers.

Mirror nuclei : These are nuclei with same A but in which neutron and proton number are interchanged.

e.g. $_4Be_3^7$ (Z = 4, N = 3) and $_3Li_4^7$ (Z = 3, N = 4)

Isomer nuclei : These are nuclei with same A and same Z but differ in their nuclear energy states. They have different life times and internal structure. These nuclei have different radioactive properties. e.g. Co^{60} & Co^{60*}

RADIOACTIVITY

The *phenomenon of spontaneous emission of radiations (α, β & γ)from a substance is called radioactivity*.
Radioactivity was discovered by Henry Becquerel in 1896 in Uranium salts. The substances like Uranium, Radium, Thorium, Polonium etc. which show radioactivity are called radioactive substances. Nuclei with Z > 83 spontaneously disintegrate with emission of α and β particles. In radioactivity emission of alpha (α), beta (β) and gamma (γ) radiation takes place. These are called radioactive radiations or Becquerel rays. The simultaneous emission of α and β particles is not possible. Only one particle is emitted at a time. The emission of radiations causes a change in structure of nucleus. This causes transformation of an atom to new lighter atom or changes a radioactive element into element of lower atomic weight. All heavier radioactive elements emit radiations till they are converted to stable $_{82}Pb^{206}$. It is a statistical process, so it is governed by the laws of probability. The disintegration of all atoms has equal probability. It is a spontaneous process which is independent of all external conditions. It is not affected by temperature, pressure, electric or magnetic field.

PROPERTIES OF α, β, AND γ RADIATION

Property	α – rays	β – rays	γ – rays
1. Nature	These are doubly ionized helium atom $_2He^4$ charge $q = +2e = 3.2 \times 10^{-19}$C mass $m = 2p + 2n = 4$amu $= 4 \times 1.6 \times 10^{-27}$ kg	These are beam of fast moving electrons ($_-\beta^0$) and positions ($_+\beta^0$) charge $_-\beta^0 = -e = -1.6 \times 10^{-19}$C $_+\beta^0 = +e = 1.6 \times 10^{-19}$C $m(_-\beta^0) = m(_+\beta^0)$ $=9.1\times10^{-31}$ kg	These are electromagnetic radiations of high frequency and travel in form of photons. charge q = 0 (chargeless) rest mass = 0 effective mass $= \frac{h\nu}{c^2} = \frac{h}{\lambda c}$
2. Speed	Speed ranges between 1.4×10^7 to 2.20×10^7 m/s $v_\alpha \sim 0.05$ c	Speed ranges from 1% to 90% of velocity of light $v_\beta \sim 0.9$c	Speed equals velocity of light $v_\gamma = c$
3. Ionising power $(\alpha > \beta > \gamma)$	These have maximum ionizing power (10000)	There ionizing power is less than α particles and more than γ rays (100)	There ionizing power is least (1)
4. Penetration power $(\alpha < \beta < \gamma)$	The penetration power is smallest. Can only penetrate through 0.01 mm thick Al sheet (1)	Penetration power is about 100 times that of α rays, can penetrate through 1 mm thick Al sheet (100)	Penetration power is very large. Can penetrate about 30 cm thick Al sheet (10000)
5. Range	Range is very small (few cms in air)	Range is more than α rays. (few meters in air)	Range is very large (many hundreds of meter in air)
6. Nature of spectrum	Line spectrum	Continuous spectrum	Line spectrum
7. Interaction with matter	Produces heat	Produces heat	Produces photoelectric effect, Compton effect and pair production
8. Effect on photo graphic plate and ZnS	Affects photographic plate and produces fluorescense on ZnS	Affects photographic plate and produces fluorescence on ZnS	Affects photographic plate and produces fluorescence on ZnS
9. Effect of electric and magnetic field	Suffers small deflection	Suffers large deflection	Pass undeflected

TYPES OF RADIOACTIVE DECAY PROCESSES

(A) Alpha (α) decay

Alpha (α) particle consists of 2 neutrons, 2 protons and carries positive charge in magnitude equal to 2 electrons. It is doubly ionized helium nuclei. α emission takes place when size of nucleus becomes too large. The decay reduces the size of nucleus. α emission is explained on the basis of quantum mechanical tunnel effect.

The energy released in α decay $Q = (M_x - M_y - M_\alpha)\, c^2$.

The kinetic energy of α particle $E_\alpha = \left(\frac{A-4}{A}\right)Q$ where A is mass number and Q is disintegration energy.

$_ZX^A$ (parent nucleus) $\longrightarrow$ $_{Z-2}Y^{A-4}$ (daughter nucleus) + $_2He^4$ (alpha particle)

e.g. $_{92}U^{238} \longrightarrow {}_{90}Th^{234} + {}_2He^4$

(B) Beta (β) decay

(i) Electron (β^-) emission : Beta β^- particles are fast moving electrons carrying negative charge. They are emitted when nucleus has too many neutrons relative to number of protons i.e. N/Z ratio is larger than required. The emission of electron takes place when a neutron is converted to proton inside the nucleus. This helps in correction of N/Z ratio.

$$_0n^1 \longrightarrow {}_1p^1 + {}_{-1}e^0 + \bar{\nu}$$

The interaction responsible for β decay is weak interaction.

$$_ZX^A \longrightarrow {}_{Z+1}Y^A + {}_{-1}e^0\ (\beta^-\ \text{particle}) + \bar{\nu}$$

e.g. $_6C^{14} \longrightarrow {}_7N^{14} + {}_{-1}e^0 + \bar{\nu}$ (antineutrino)

(ii) Positron (β^+) emission : Beta β^+ particles are positrons with mass equal to an electron but carry a unit positive charge. They are emitted when nucleus has too many protons relative to number of neutrons i.e. N/Z ratio is smaller than required. The emission of positron takes place when a proton is converted to neutron inside the nucleus. This increases N/Z ratio .

$$_1p^1 = {}_0n^1 + {}_{+1}e^0 + \nu$$

$$_ZX^A \longrightarrow {}_{Z-1}X^A + {}_{+1}e^0\ (\beta^+\ \text{particle}) + \nu$$

eg. $_{29}Cu^{64} \longrightarrow {}_{28}Ni^{64} + {}_{+1}e^0 + \nu$ (neutrino)

(C) Gamma (γ) decay

Gamma γ rays are electromagnetic radiations which are chargeless, massless and emitted when nucleus has excess energy. They are emitted when nucleus jumps from excited state to lower level or ground state. This reduces the energy of nucleus. They are electromagnetic radiations of short wavelength ($\sim 10^{-12}$m) which travel with speed of light.

$$_ZX^{A*} \longrightarrow {}_ZX^A + \gamma$$

e.g. $_5B^{12} \longrightarrow {}_6C^{12*} + {}_{-1}e^0 + \bar{\nu}$

$$_6C^{12*} \longrightarrow {}_6C^{12} + \gamma$$

(D) Electron capture

This process takes place when nucleus has too many protons relative to number of neutrons i.e. N/Z ratio is larger than required. In this process parent nucleus captures one of its own orbital atomic electron and emits a neutrino.

In most cases, it is k-shell electron that is captured and for this reason this process is referred to as **k-capture.**

$$_ZX^A + {}_{+1}e^0 \longrightarrow + {}_{Z-1}Y^A + \nu$$

e.g. $_4Be^7 + {}_{-1}e^0 \longrightarrow {}_3Li^7 + \nu$

Soddy and Fajan's Displacement Laws

1. **For alpha (α) decay :** When a radioactive element emits an α particle, the new element has mass number A reduced by 4 and atomic number Z reduced by 2. The new element is displaced by two places on left in periodic table.

$$_ZX^A \longrightarrow {}_{Z-2}Y^{A-4} + {}_2He^4$$

2. **For beta (β^-) decay :** When an element emits a β^- particle the mass number A remains unchanged and atomic number Z is increased by 1 . The new element is displaced by one place on right in periodic table

$$_ZX^A \longrightarrow {}_{Z+1}Y^A + {}_{-1}e^0 + \text{antineutrino}\ (\bar{\nu})$$

3. **For positron (β^+) decay :** When an element emits a β^+ particle the mass number remains unchanged and atomic number Z is decreased by one. The new element is displaced by one place on left in periodic table

$${}_{Z}X^{A} \longrightarrow {}_{Z-1}Y^{A} + {}_{+1}e^{0} + \text{neutrino}\,(\nu)$$

4. **For gamma (γ) decay :** When an element emits a γ particle the mass, charge or position of element in periodic table remains unchanged. Here the excited nucleus returns to ground state by emission of γ ray photon.

LAW OF RADIOACTIVE DECAY, DECAY CONSTANT, HALF-LIFE AND MEAN LIFE

Law of Radioactive Decay

The disintegration of a radioactive substance is random and spontaneous. Radioactive decay is purely a nuclear phenomenon and is independent of any physical and chemical conditions. The radioactive decay follows first order kinetics, i.e., the rate of decay is proportional to the number of undecayed atoms in a radioactive substance at any time t. If dN be the number of atoms (nuclei) disintegrating in time dt, the rate of decay is given as dN/dt.

From first order of kinetic rate law: $\frac{dN}{dt} = -\lambda N$ where λ *is called as decay or disintegration constant.*

Let N_0 be the number of nuclei at time t = 0 and N_t be the number of nuclei after time t, then according to integrated first order rate law, we have

$$N_t = N_0 e^{-\lambda t}$$

$$\Rightarrow \lambda t = \ln\frac{N_0}{N_t} = 2.303\log\frac{N_0}{N_t}$$

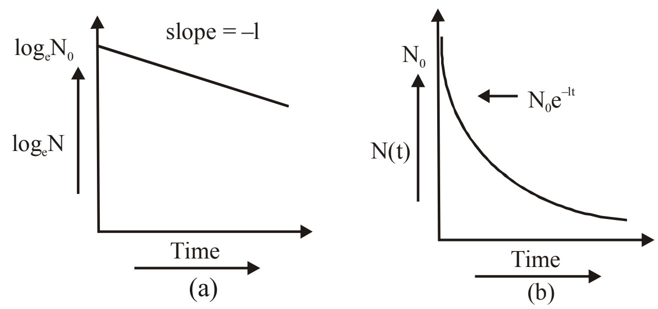


Fig. 8.10

The fraction of active atoms remaining at time t is

$$\frac{N}{N_0} = e^{-\lambda t}$$

The number of atoms that have decayed in time t is $N_0 - N = N_0(1 - e^{-\lambda t})$

The fraction of atoms that have decayed in time t is $\frac{N_0 - N}{N_0} = 1 - e^{-\lambda t}$

Decay Constant

Decay constant is rate of decay of radioactive atoms per active atom.

$$\text{Decay constant, } \lambda = \frac{-dN/dt}{N} = \frac{\text{rate of decay}}{\text{number of active atoms}}$$

At $t = \frac{1}{\lambda}$; $\quad N = \frac{N_0}{e}$

The decay constant of radioactive element is equal to reciprocal of the time after which number of remaining active atoms reduce to 1/e times of original value.

At $t = \frac{1}{\lambda}$ fraction of active nuclei left $= \frac{N}{N_0} = \frac{1}{e} = 0.37$ or 37%

Hence, fraction of decayed nuclei $= 1 - \frac{N}{N_0} = 0.63 = 63\%$

The **S.I. unit** of decay constant is second^{-1} and **dimension** is $[M^0 L^0 T^{-1}]$

If there are more than one radioactive elements in a group then the resultant decay constant is equal to sum of individual decay constants.

$$\lambda eq = \lambda_1 + \lambda_2 + \lambda_3 + ... \text{ and } \frac{1}{T} = \frac{1}{T_1} + \frac{1}{T_2} + ...$$

Radioactive equilibrium : When the rate of formation of daughter nuclei becomes equal to rate of its decay then this is called as state of radioactive equilibrium $N_A\lambda_A = N_B\lambda_B = ...$ or $\frac{N_A}{T_A} = \frac{N_B}{T_B} = ...$

Half-life (T)

The *half-life period* (T) *of a radioactive substance is defined as the time in which one-half of the radioactive substance is disintegrated*. If N_0 be the number of nuclei at t = 0, then in a half life T, the number of nuclei decayed will be $N_0/2$.

$$N_t = N_0 e^{-\lambda t} \qquad ...(i) \qquad \frac{N_0}{2} = N_0 e^{-\lambda T} \qquad ...(ii)$$

From eqs. (i) and (ii) $\frac{N_t}{N_0} = \left(\frac{1}{2}\right)^{t/T} = \left(\frac{1}{2}\right)^n$ here, n = number of half lives

Also, $T = \frac{0.693}{T}$

Mean Life (τ)

The mean life of an atom in a radioactive substance is called average life of radioactive substance.

Mean life $\tau = \frac{\text{the sum of lives of all active atoms}}{\text{total number of active atoms}}$ or $\tau = \frac{\int_0^{N_0} t\, dN}{N_0} = \frac{N_0\lambda \int_0^{N_0} t\, e^{-\lambda} dt}{N_0} = \frac{1}{\lambda}$

Thus mean life is equal to reciprocal of decay constant $(\tau = 1/\lambda)$

Half life $T = \frac{0.693}{\lambda} = 0.693\tau$ and mean life $\tau = \frac{T}{0.693} = 1.44T$

Clearly $\tau > T$ i.e. Average life is greater than half life.
Mean life is the time in which number of active atoms reduces to 37% of its initial value or number of decayed atoms is 63%

$N = N_0 e^{-\lambda t}$ so $\log \frac{N}{N_0} = -\lambda t$

Mean life is equal to magnitude of reciprocal of slope of $\log \frac{N}{N_0}$ v/st curve.

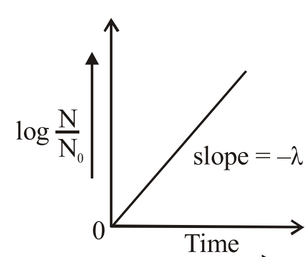


Fig. 8.11

Activity of Radioactive Substance

The number of decays per unit time or decay rate is called activity.

Activity $A = \frac{dN}{dt} = N_0\lambda e^{-\lambda t} = A_0 e^{-\lambda t} = N\lambda$

where $N_0\lambda = A_0$ is initial activity

$A = A_0 e^{-\lambda t}$ is the activity law which shows activity decreases exponentially with time.

The activity of one gram of radioactive substance called **specific activity**.

Units of activity

Curie : The specific activity of 1 gm of Radium 226 is called one curie.

1 curie = 3.7×10^{10} disintegrations per second

Rutherford : 1 rutherford = 10^6 disintegrations per second

Becquerel : 1 becquerel = 1 disintegration per second

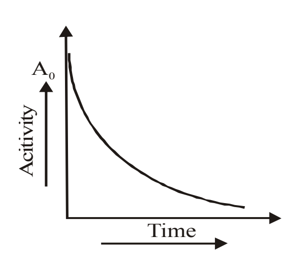


Fig. 8.12

RADIOACTIVE SERIES AND CARBON DATING

Radioactive Series

The heavy nuclides change their mass number by a decay and atomic number by a and b decay.

They can decay to stable end products by four paths. The four paths have mass numbers given as 4n, 4n + 1, 4n + 2, 4n + 3 where n is an integer.

Last element of radioactive series is stable and has a decay constant zero.

Series	Mass number	Starting isotope	Stable end product	Natural/Artificial
Thorium	4n	${}_{90}Th^{232}$	${}_{82}Pb^{208}$	Natural
Neptunium	4n+1	${}_{93}Np^{237}$	${}_{83}Bi^{209}$	Artificial
Uranium	4n+2	${}_{92}U^{238}$	${}_{82}Pb^{206}$	Natural
Actinium	4n+3	${}_{92}U^{235}$	${}_{82}Pb^{207}$	Natural

Carbon Dating

Carbon dating is the process of determination of time interval which has passed by making use of radioactive decay of a sample containing radioactive substance. It helps in calculating age of geological specimens like rocks, biological specimens like bones of animals or trunk of trees and age of earth. The isotope of carbon ${}_6C^{14}$ is radioactive.

It is formed in atmosphere by bombardment of nitrogen atoms with cosmic rays

$$ {}_7N^{14} + {}_0n^1 \rightarrow {}_6C^{14} + {}_1H^1 $$

The ${}_6C^{14}$ combines with oxygen to form carbondioxide which is absorbed by plants so concentration of ${}_6C^{14}$ is constant with time. The living plants and animals have a fixed ratio of ${}_6C^{14}$ to ordinary carbon ${}_6C^{12}$. When a plant or animal dies the content of ${}_6C^{14}$ decreases while that of ${}_6C^{12}$ remains constant. The ratio of two indicates the time that has passed since death of plant or animal. The time interval is calculated from the laws of radioactive disintegration.

$$ t = \frac{1}{\lambda}\log_e \frac{N_0}{N} = \frac{2.303}{\lambda}\log_{10}\frac{N_0}{N} \quad \left(\frac{N_0}{N} = \frac{A_0}{A}\right) $$

where N_o is number of ${}_6C^{14}$ nuclei at the time of death, λ is decay constant of ${}_6C^{14}$ and N is number of ${}_6C^{14}$ nuclei currently present in sample.

ILLUSTRATION 8.9

How long will it take for a radioactive sample to decrease to 10%, if its half life is 22 years?

SOLUTION :

Using $\frac{N}{N_0} = \left(\frac{1}{2}\right)^{t/T}$ we get $\left(\frac{1}{2}\right)^{t/22} = \frac{10}{100}$

or $10 = 2^{t/22}$ or $\log_{10} 10 = \frac{t}{22}\log_{10} 2$

$$ t = \frac{22\ \log_{10} 10}{\log_{10} 2} = \frac{22 \times 1}{0.3010} \approx 73 \text{ years.} $$

ILLUSTRATION 8.10

The charcoal sample showed a C^{14} activity of 11.3 counts/g min . The absolute activity of C^{14} is 15.3 counts/g min. Estimate the age of charcoal sample. Half life of C^{14} is 5568 years.

SOLUTION :

Here, A_0 = 15.3 counts/g - min, A = 11.3 counts/g-min and half life T = 5568 years

$$ \lambda = \frac{0.693}{T} = \frac{0.693}{5568} \text{ per year} $$

Age of sample, $t = \frac{2.303}{\lambda}\log_{10}\frac{A_0}{A} = \frac{2.303 \times 5568}{0.693}\log_{10}\frac{15.3}{11.3} = \frac{2.303 \times 5568 \times 0.1316}{0.693} = 2434$ years

ILLUSTRATION 8,11

A radioactive nucleus decays as $X \xrightarrow{\alpha} X_1 \xrightarrow{\beta^-} X_2 \xrightarrow{\alpha} X_3 \xrightarrow{\gamma} X_4$

If mass number and atomic number of X are 180 and 72 then find these values of X_4.

SOLUTION :

$$_{72}X^{180} \xrightarrow{\alpha} {}_{70}X_1^{176} \xrightarrow{\beta^-} {}_{71}X_2^{176} \xrightarrow{\alpha} {}_{69}X_3^{172} \xrightarrow{\gamma} {}_{69}X_4^{172}$$

Hence, mass number and atomic number of x_4 are 172 and 69 respectively.

ILLUSTRATION 8.12

A count- rate meter is used to measure the activity of a given sample. At one instant the meter shows 4750 counts per minute. Five minutes later it shows 2700 counts per minute. Find decay constant and the half life of the sample.

SOLUTION :

Initial activity, $A_0 = dN/dt$ at $t = 0$
Final activity, $A_t = dN/dt$ at $t = t$

$$\left.\frac{dN}{dt}\right|_{t=0} = \lambda N_0 \quad \text{and} \quad \left.\frac{dN}{dt}\right|_{t=5} = \lambda N_t \Rightarrow \frac{4750}{2700} = \frac{N_0}{N_t}$$

Using, $\lambda t = 2.303 \log \frac{N_0}{N_t} \Rightarrow \lambda(5) = 2.303 \log \frac{4750}{2700}$

$\Rightarrow$ Decay constant $\lambda = \frac{2.303}{5} \log \frac{4750}{2700} = 0.1129\,\text{min}^{-1}$ and half life $t_{1/2} = \frac{0.693}{0.1129} = 6.14$ min.

MISCELLANEOUS SOLVED EXAMPLES

1. Find the ratio of the area of orbit of first excited state of electron to the area of orbit of ground level for hydrogen atom.

Sol. As we know, area $A \propto r^2 \propto n^4$ ($\because$ radius $r \propto n^2$)

Ratio of area of orbits, $\frac{A_2}{A_1} = \left[\frac{2}{1}\right]^4 = \frac{16}{1} = 16:1$

2. The activity of a radioactive substance drops to 1/32 of its initial value in 7.5 h. Find the half life of the radioactive subustance.

Sol. Using $\frac{A}{A_0} = \left(\frac{1}{2}\right)^{t/T}$ or $\frac{1}{32} = \left(\frac{1}{2}\right)^{7.5/T}$

or $\left(\frac{1}{2}\right)^5 = \left(\frac{1}{2}\right)^{7.5/T}$ or $5 = \frac{7.5}{T}$ $\therefore$ $T = 1.5$ hours

3. The half life of a radioactive substance is 34.65 minute. If 10^{22} atoms are active at any time then find the activity of substance?

Sol. Here, half life T = 34.65 minute = 34.65 × 60s N = 10^{22}

Activity A = $\frac{-dN}{dt} = \lambda N$

$A = \frac{0.693}{T} \times N = \frac{0.693}{34.65 \times 60} \times 10^{22} = 3.34 \times 10^{18}$ disintegration /sec.

4. The mean life of a radioactive material for α and β decay are 1620 years and 520 years. What is the half life of sample.

Sol. Here, T_α = 1620 years; T_β = 520 years; half life T = ?

There are two channels of decay so $\frac{1}{\tau} = \frac{1}{\tau_\alpha} + \frac{1}{\tau_\beta}$ or $\tau = \frac{\tau_\alpha \tau_\beta}{\tau_\alpha + \tau_\beta} = \frac{1620 \times 520}{1620 + 520} = 394$ years

The half life $T = 0.693\tau = 0.693 \times 394 = 273$ years

5. The binding energy of $_{10}Ne^{20}$ is 160.64 MeV. Find the atomic mass. m_P = 1.007825 amu and m_n = 1.008665 amu

Sol. Binding energy $BE = \Delta mc^2 = c^2\,[Zm_P + (A-Z)\,m_n - M]$

$M = Zm_p + (A-Z)\,m_n - BE$(amu)

$M = 10 \times 1.007825 + 10 \times 1.008665 - \frac{160.64}{931.25} = 19.992$ amu.

6. How many α and β particles are emitted when $_{90}Th^{232}$ converts to $_{82}Pb^{208}$.

Sol. Change in mass number ΔA = 232–208 = 24

Mass number (A) changes only in α decay so number of α particles = 24/4 = 6

This decreases atomic number, Z by 6 × 2 = 12 giving final Z = 90 – 12 = 78

But final Z given is 82.

Beta β^- emission increases Z by 1

so, no. of β^- particle = 82 – 78 = 4

7. Ultraviolet light of wavelength 2271Å from a 100 W mercury source irradiates a photo-cell made of molybdenum metal. If the stopping potential is – 1.3 V, estimate the work function of the metal. How would the photo-cell respond to a high intensity (~10^5 W m^{-2}) red light of wavelength 6328Å produced by a He-Ne laser?

Sol. Let us find energy of each photon of given ultraviolet light

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{2271 \times 10^{-10} \times 1.6 \times 10^{-19}} = 5.47 \text{ eV} \qquad (\because \lambda = 2271\text{ Å given})$$

Maximum kinetic energy of emitted electron can be judged by stopping potential of 1.3 volt.

$\frac{1}{2}mv_{\max}^2 = 1.3$ eV

Using Einstein's equation $h\upsilon = W_0 + \frac{1}{2}mv_{\max}^2$

5.47 eV = W_0 + 1.3 eV $\Rightarrow W_0$ = 4.17 eV

Red light of wavelength 6328Å will have energy of each photon

$$E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{6328\times10^{-10}\times1.6\times10^{-19}} = 1.96\,\text{eV} \ (\because 1 = 227\text{A}^\text{o} \text{ given})$$

Thus energy of red light photons is less than work function 4.17 eV, hence irrespective of any intensity no emission will take place.

8. 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 answer above would change if the choice of the zero of potential energy is changed?

Sol. Kinetic energy of an electron in an orbit, $K = \frac{1}{4\pi\varepsilon_0}\frac{e(Ze)}{2r}$ ...(i)

Potential energy of an electron in an orbit $U = -\frac{1}{4\pi\varepsilon_0}\left(\frac{Ze^2}{r}\right)$ ...(ii)

Total energy $E = K + U = -\frac{1}{4\pi\varepsilon_0}\left(\frac{Ze^2}{2r}\right) = -K = \frac{U}{2}$

It is given, total energy $E = (-3.4\text{ eV})$
(a) Kinetic energy of electron in this state $E = -K$
So, $K = E = -\ (-3.4\text{ eV}) = 3.4\text{ eV}$
(b) Potential energy $E = U/2$
$U = 2E = 2\,(-3.4) = -6.8\text{ eV}$
(c) If the zero of the potential energy is chosen differently, the kinetic energy remain the same. Althugh potential energy and hence total energy changes.

9. A radioactive isotope has a half-life of *T* years. How long will it take the activity to reduce to (a) 3.125%, (b) 1% of its original value?

Sol. Activity $R = R_0 e^{-\lambda t}$

Also instantaneous activity, $R = -\lambda N$ $\quad R = -\frac{0.693}{T}N$

Initital activity, $R_0 = -\lambda N_0$ $\quad$ So, $R_0 = -\frac{0.693}{T}N_0$

(a) $\frac{R}{R_0} = \frac{N}{N_0} = \frac{3.125}{100} = \frac{1}{32}$ or $\frac{N}{N_0} = \left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^5$ or $n = 5$ $\quad \therefore\ t = nT = 5T$ years.

(b) $\frac{R}{R_0} = \frac{N}{N_0} = \frac{1}{100}$

Required time, as cannot be solved by direct calculation as in part (a).

$$t = \frac{2.303}{\lambda}\log\frac{N_0}{N} = \frac{2.303T}{0.693}\log 100 = \frac{2.303\times2\times T}{0.693} \approx 6.65T \text{ years.}$$

10. The half-life of $^{90}_{38}$Sr is 28 years. What is the distintegration rate of 15 mg of this isotope?

Sol. Given: $T_{1/2} = 28$ years $= 28 \times 3.154 \times 10^7$s
Mass $m = 15$ mg $= 0.015$g

Number of atoms in 0.015g sample of $^{80}_{38}$Sr,

$$N = \frac{m}{M}\times\text{Avogadro's number} = \frac{0.015\times6.023\times10^{23}\text{ atoms}}{90}$$

Activity of the sample, $R = \lambda / N = \frac{0.693}{T_{1/2}}N = \frac{0.693\times0.015\times6.023\times10^{23}}{28\times3.154\times10^{7}\times90}$

$= 7.877 \times 10^{10}$ disintegration/sec $= 7.877 \times 10^{10}$ Bq $= \frac{7.877\times10^{10}}{3.7\times10^{10}}$ Ci $= 2.13$ Ci.

EXERCISE

DIRECTIONS (Qs. 1-28) : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. The volume occupied by an atom is greater then the volume of the nucleus by a factor of about
(a) 10^1 (b) 10^5
(c) 10^{10} (d) 10^{15}

2. Which of the following is true for isotopes of specimen of U^{235} and U^{238}?
(a) both contain same number of neutrons
(b) both contain same of number of proton, electron and neutron
(c) both contain same number of proton and electron but U^{238} contains three more neutrons than U^{235}
(d) U^{238} contain three less neutrons than U^{235}

3. Atomic nucleus contains
(a) electron & photon
(b) electron, proton & neutron
(c) electron & neutron
(d) proton & neutron

4. The atomic number & mass number of element is Z & m then number of neutron will be
(a) $m \times z$ (b) $m + z$
(c) m/z (d) $m - z$

5. Nuclei containing different number of protons but same number of neutrons are called
(a) Iso clinics (b) isobars
(c) isotones (d) isotopes

6. 1 amu is equivalent to
(a) 9.31 MeV (b) 931 KeV
(c) 93.1 MeV (d) 931 MeV

7. The dependence of density [d] of nuclear matter on the mass number A is
(a) $d \propto A$ (b) $d \propto \sqrt{A}$
(c) d = const. (d) $d \propto 1/A$

8. The wrong statement is
(a) Nuclear forces are strongest
(b) Nuclear forces are very short range forces
(c) Nuclear force increase when the number of nucleons is increased
(d) Nuclear force is produced by the exchange of pions

9. Range of nuclear force is approximately
(a) 2×10^{-10} m (b) 1.5×10^{-20} m
(c) 7.2×10^{-4} m (d) 1.4×10^{-15} m

10. The mass number of a nucleus is equal to the number of
(a) Electron it contains (b) Protons it contains
(c) Neutrons it contains (d) Nucleons it contains

11. The neutron was discovered by
(a) Marie Curie (b) Pierre Curie
(c) James Chadwick (d) Rutherford

12. The order of magnitude of the density of nuclear matter is
(a) 10^4 kg/m^3 (b) 10^{17} kg/m^3
(c) 10^{27} kg/m^3 (d) 10^{34} kg/m^3

13. Force between protons in nucleus will be
(a) only nuclear (b) only coulomb
(c) nuclear & coulomb (d) coulomb & gravitational

14. The mass equivalent of 931 MeV energy is
(a) 1.66×10^{-27} kg (b) 6.02×10^{-24} kg
(c) 1.66×10^{-20} kg (d) 6.02×10^{-27} kg

15. When four hydrogen nuclei fuse together to form helium nucleus, then in this process
(a) Energy is absorbed.
(b) Energy is liberated.
(c) Absorption and liberation of energy depends upon the temperature.
(d) Energy is neither liberated nor absorbed.

16. Two lighter nuclei are fused together to form a nucleus of medium atomic mass and energy is released in this process because
(a) Binding energy of lighter nuclei is more.
(b) Binding energy per nucleon of lighter nuclei is more.
(c) Binding energy per nucleon of medium nucleus is more.
(d) Energy is always released when two nuclei are fused.

17. In atomic explosion, a temperature of about 10 million degrees is developed at the moment of explosion. The wavelength of light coming from the hot region of the atomic explosion lie in the region
(a) ultraviolet region (b) visible region
(c) infrared region (d) x-ray region

18. When light is incident on surface, photo electrons are emitted. For photoelectrons
(a) The value of kinetic energy is same
(b) Kinetic energy does not depend on the wave length of incident light
(c) The value of kinetic energy is equal to or less than a maximum energy
(d) None of the above

19. The phenomenon of photo electric emission depends on
(a) Only wave length of incident light
(b) Only work function of surface
(c) Only nature of surface
(d) All of the above

20. Photo electric effect is the phenomenon in which
(a) Photons come out of a metal when it is hit by a beam of electrons
(b) Photons come out of the nucleus of an atom under the action of an electric filed
(c) Electrons come out of metal with a constant velocity depending on frequency and intensity of incident light
(d) Electrons come out of a metal with different velocity not greater than a certain value which depends only on the frequency of the incident light wave and not on its intensity.

21. The electrons are emitted in the photo electric effect from a metal surface
(a) Only if the frequency of radiation is above a certain threshold value
(b) Only if the temperature of the surface is high
(c) At a rate that is independent of the nature of metal
(d) With a maximum velocity which is proportional to the frequency of incident radiation

22. Work function is
(a) Energy necessary to eject the electron from its orbit
(b) Energy necessary to eject the electron from metal
(c) Minimum necessary energy to eject the electron from metal
(d) Wavelength necessary for releasing an electron from a body

23. Einstein got noble prize for
(a) Photo electric effect (b) Compton effect
(c) Theory of relativity (d) None of the above

24. A radioactive substance has a half life of four months. Three fourth of the substance will decay in
(a) Three months (b) Four months
(c) Eight months (d) Twelve months

25. When hydrogen atom is in its first excited level, it's radius is
(a) Four times, it ground state radius
(b) Twice times, it ground state radius
(c) Same times, it ground state radius
(d) Half times, it ground state radius.

26. If N_0 is the original mass of the substance of half-life period $t_{1/2}$ = 5 years, then the amount of substance left after 15 years is
(a) $N_0/8$ (b) $N_0/16$
(c) $N_0/2$ (d) $N_0/4$

27. If mass-energy equivalence is taken into account, when water is cooled to form ice, the mass of water should
(a) increase
(b) remain unchanged
(c) decrease
(d) first increase then decrease

28. Which of the following ***cannot*** be emitted by radioactive substances during their decay?
(a) Protons (b) Neutrinoes
(c) Helium nuclei (d) Electrons

DIRECTIONS (Qs. 29-46) : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

29. 9.1×10^{-34} kg
(a) 0.51 MeV (b) 9.1×10^{-28} gm
(c) 0.0005477 amu (d) none of these

30. According to Bohr's theory of hydrogen atom, for the electron in the nth allowed orbit, the
(a) linear momentum is proportional to $(1/n)$
(b) radius is proportional to n
(c) the kinetic energy is proportional to $(1/n^2)$
(d) the angular momentum is proportional to n

31. An electron orbiting in a circular orbit around the nucleus of an atom
(a) has a magnetic dipole moment
(b) exerts an electric force on the nucleus equal to that on it by the nucleus
(c) does produces a magnetic induction at the nucleus
(d) has a net energy inversely proportional to its distance from the nucleus

32. A particular hydrogen like atom has its ground state binding energy 122.4 eV. Then
(a) its atomic number is 3
(b) an electron with 90 eV energy can interact with it and excite it
(c) an 80 eV electron emerges when an 80 eV electron interacts with it
(d) an electron of 8.2 eV and a photon of 91.8 eV are emitted when a 100 eV electron interacts with this atom

33. In which of the following situations the heavier of the two particles has smaller de Broglie wavelength? The two particles
(a) move with the same speed
(b) move with the same linear momentum
(c) move with the same kinetic energy
(d) have fallen through the same height

34. In the hydrogen atom in the ground state
(a) the kinetic energy of the electron is less than the potential energy which is positive
(b) the potential energy is less than the kinetic energy which is positive
(c) the potential energy is negative and the kinetic energy numerically less than the numerical value of potential energy
(d) the total energy is negative

35. Mark the correct options
(a) An atom with a vacancy has a smaller than the neutral atom
(b) K X-ray is emitted when a hole makes a jump from the K-shell to some other shell
(c) The wavelength of K X-ray is smaller than the wavelength of L X-ray of the same material
(d) The wavelength of K_α X-ray is smaller than the wave length of K_β X-ray of the same material

36. Who was/were won the novel prize of physics in 1903?
(a) Pierre Curie (b) Becquerel
(c) Rutherford (d) Madame Curie

37. When the nucleus of an electrically neutral atom undergoes a radioactive decay process, it will remain neutral after the decay if the process is
(a) an α-decay (b) a β-decay
(c) a γ-decay (d) a K-capture process

38. When a nucleus with atomic number Z and mass number A undergoes a radioactive decay process
(a) both Z and A will decrease if the process is α-decay
(b) Z will decrease but A will not change if the process is β^+ - decay
(c) Z will increase but A will not change, if the process is β^-- decay
(d) Z and A will remain unchanged if the process is γ - decay

39. During a β^-- decay which of the following statements are correct?
(a) The daughter nucleus has one proton less than the parent nucleus
(b) The daughter nucleus has one proton more than the parent nucleus
(c) An electron which is already present within the nucleus is rejected
(d) A neutron in the nucleus decays emitting an electron

40. The decay constant of a radioactive substance is 173 $(\text{years})^{-1}$. Therefore
(a) nearly 63% of the radioactive substance will decay in 0.173 years
(b) half-life of the radioactive substance is (1/0.173) year
(c) one-fourth of the radioactive substance will be left after 8 years
(d) all the above statements are true

41. Which of the following reactions are not possible?
(a) $p \to n$ + positron + energy
(b) $n \to p$ + electron + energy
(c) ${}_{13}\text{A1}^{27} + {}_{1}\text{H1}^{2} \to {}_{12}\text{Mg}^{25} + {}_{2}\text{He}^{4}$
(d) ${}_{92}\text{U}^{235} + {}_{0}n^{1} \to {}_{54}\text{Xe}^{140} + {}_{38}\text{Sr}^{95} + 2\,{}_{0}n^{1} + \gamma$

42. The probability of disintegration per second of a nucleus in a given radioactive sample
(a) increases proportional to the life time lived by the nucleus
(b) decreases with the life time lived
(c) is independent of the life time lived
(d) depends on the total number of identical nuclei present in the sample

43. The heavier nuclei tend to have larger N/Z ratio because
(a) a neutron is heavier than a proton
(b) a neutron is an unstable particle
(c) a neutron does not exert electric repulsion
(d) Coulomb force has longer range as compared to the nuclear force

44. ${}_{92}\text{U}^{235}$ is an alpha active nucleus. Then in a large quantity of the element
(a) the probability of a nucleus disintegrating during one second is lower in the first half-life and greater in the fifth half-life
(b) the probability of a nucleus disintegrating during one second remains constant for all the time
(c) quite an appreciable quantity of U^{235} will remain, even after average life
(d) the energy of emitted α-particle is less than the disintegration energy of the U^{235} nucleus

45. During the radioactive decay
(a) atomic mass number cannot increase
(b) atomic number may increase
(c) atomic number may decrease
(d) atomic number may remain unchanged

46. An electron in a hydrogen atom makes a transition $n_1 \to n_2$ where n_1 and n_2 are principle quantum numbers of the two state. Assume the Bohr model to be valid. The time period of the election in the initial state is eight times that in the final state. The possible values of n_1 and n_2 are
(a) $n_1 = 4, n_2 = 2$ (b) $n_1 = 8, n_2 = 2$
(c) $n_1 = 8, n_2 = 1$ (d) $n_1 = 6, n_2 = 3$

DIRECTIONS (Qs. 47-52) : *Study the given paragraph(s) and answer the following questions.*

Passage - 1

A physicist wishes to eject electrons by shining light on a metal surface. The light source emits light of wavelength of 450 nm. The table lists the only available metals and their work functions.

Metal	W_0 (eV)
Barium	2.5
Lithium	2.3
Tantalum	4.2
Tungsten	4.5

47. Which metal(s) can be used to produce electrons by the photoelectric effect from given source of light ?
(a) Barium only
(b) Barium or lithium
(c) Lithium, tantalum or tungsten
(d) Tungsten or tantalum

48. Which option correctly identifies the metal that will produce the most energetic electrons and their energies ?
(a) Lithium, 0.45 eV (b) Tungston, 1.75 eV
(c) Lithium, 2.30 eV (d) Tungston, 2.75 eV

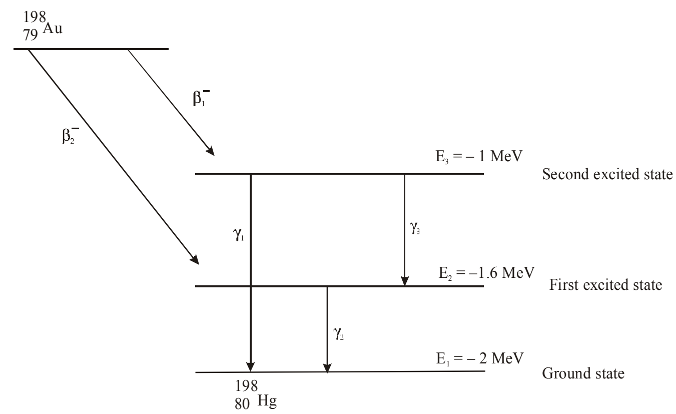
49. Suppose photoelectric experiment is done separately with these metals with light of wavelength 450 nm. The maximum magnitude of stopping potential amongst all the metals is-
(a) 2.75 volt (b) 4.5 volt
(c) 0.45 volt (d) 0.25 volt

Passage - II

Gold nucleus (${}_{79}\text{Au}^{198}$) can decay into mercury nucleus (${}_{80}\text{Hg}^{198}$) by two decay schemes shown in figure. (i) it can emit a β particle (β_1) and come to ground state by either emitting one γ ray (γ_1) or emitting two γ rays (γ_3 & γ_4) (ii) it can emit one β particle (β_2) and come to ground state by emitting γ_2 ray.

Atomic masses : ${}^{198}\text{Au} = 197.9682$ amu ,

${}^{198}\text{Hg} = 197.9662$ amu , 1 amu = 930 MeV/c². The energy levels of the nucleus are shown in figure.



50. What is the maximum kinetic energy of emitted β_2 particles–

(a) 1.44 MeV (b) 0.59 MeV
(c) 1.86 MeV (d) 1.46 MeV

51. What is the maximum kinetic energy of emitted β_1 particle is –

(a) 1.28 MeV (b) 0.77 MeV
(c) 1.86 MeV (d) 0.86 MeV

52. The wavelength of emitted γ rays are in the other –

(a) $\lambda_{\gamma_2} > \lambda_{\gamma_3} > \lambda_{\gamma_1}$ (b) $\lambda_{\gamma_3} > \lambda_{\gamma_2} > \lambda_{\gamma_1}$
(c) $\lambda_{\gamma_1} > \lambda_{\gamma_2} > \lambda_{\gamma_3}$ (d) $\lambda_{\gamma_3} = \lambda_{\gamma_2} = \lambda_{\gamma_1}$

DIRECTIONS (Qs. 53-58) : *Each of these questions contains an Assertion followed by Reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.
(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.
(c) If **Assertion** is **correct** but **Reason** is **incorrect**.
(d) If **Assertion** is **incorrect** but **Reason** is **correct**.

53. Assertion : Nuclear forces are independent of charges.
Reason : Nuclear force is not a central force.

54. Assertion : The strength of photoelectric current depends upon the intensity of incident radiation.
Reason : A photon of energy E (= hν) possesses a mass equal to E/c² and momentum equal to E/c.

55. Assertion : Binding energy (or mass defect) of hydrogen nucleus is zero.
Reason : Hydrogen nucleus contain only one nucleon.

56. Assertion : The rest mass energy of a nucleus is smaller than the rest mass energy of its constituent nucleons in free state.
Reason : Nucleons are bound together in a nucleus.

57. Assertion : In a decay process of a nucleus, the mass of products is less than that of the parent.
Reason : The rest mass energy of the products must be less than that of the parent.

58. Assertion : In street light circuits, photo-cells are used to switch on and off the lights automatically at dusk and dawn.
Reason : A photocell can convert a change in intensity of illumination into a change in photocurrent that can be used to control lighting system.

DIRECTIONS (Q. 59) : *Following question has four statements (A, B, C and D) given in Column I and 5 statements (p, q, r, s and t) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

59. Match the following

	Column – I		Column – II
A.	Isobars	(p)	Saturation
B.	Isotones	(q)	Same mass number
C.	Isotopes	(r)	Different chemical properties
D.	Nuclear force	(s)	Same atomic number
		(t)	Non-central

	A	B	C	D
(a)	r	r, s, t	s	p, q, r
(b)	s	p	q	r, t
(c)	p, q	s	r, s, t	q
(d)	q, s	q, r	s	s, t

DIRECTIONS (Qs. 60-65) : *Following are integer based/Numeric based questions. Each question, when worked out will result in one integer or numeric value.*

60. The mean lives of a radio-active substances are 1620 years and 405 years for α-emission and β-emission respectively. Find out the time during which three-fourth of a sample will decay if it is decaying both by α-emission and β-emission simultaneously.

61. Find the binding energy per nucleon for a lithium nucleus $_3Li^7$. Take mass of $_3Li^7$ = 7u, mass of proton 1.007825 u and mass of neutron = 1.008665 u. Take 1 u = 931.5 MeV.

62. Using E = mc^2, find out the energy released, when 1 u of mass disappears.
Take 1 u = 1.66×10^{-27} kg.

63. x- alpha and y-beta particles are emitted when uranium ($_{92}U^{238}$) decays to lead $_{82}Pb^{206}$. The value of x and y are ?

64. A radioactive nucleus undergoes a series of decay according to the scheme

$$\mathbf{A \xrightarrow{\alpha} A_1 \xrightarrow{\beta^-} A_2 \xrightarrow{\alpha} A_3 \xrightarrow{\gamma} A_4}.$$

If the mass number and atomic number of A are 180 and 72 respectively, what are these numbers for A_4?

65. Some amount of a radioactive substance (half life = 10 days) is spread inside a room and consequently the level of radiation becomes 50 times permissible level for normal occupancy of the room. After how many days the room will be safe for occupation?

SOLUTIONS

Brief Explanations of Selected Questions

EXERCISE

1.	(c)	**2.**	(c)	**3.**	(d)	**4.**	(d)	**5.**	(c)
6.	(d)	**7.**	(c)	**8.**	(c)	**9.**	(d)	**10.**	(d)
11.	(c)	**12.**	(b)	**13.**	(c)	**14.**	(a)	**15.**	(b)
16.	(c)	**17.**	(d)	**18.**	(c)	**19.**	(d)	**20.**	(c)
21.	(a)	**22.**	(c)	**23.**	(a)				

24. (c) Substance left undecayed - $N_0 - \frac{3}{4}N_0 = \frac{1}{4}N_0$

$$\frac{N}{N_0} = \frac{1}{4} = \left(\frac{1}{2}\right)^n$$

$\therefore$ n = 2 i.e. in two half lives

$\therefore$ t = nT = 2 × 4 = 8 months

25. (a) $r_n = r_o.n^2$, where r_o is radius of G-state & r_n is radius of n^{th} state. (For first excited state n = 2).

26. (a) Amount left = $N_0/2^n = N_0/8$ (Here n = 15/5 = 3)

27. (a) Because thermal energy decreases, therefore mass should increase.

28. (a)

29.	(b, c)	**30.**	(a, c, d)	**31.**	(a, b, c, d)
32.	(a, c, d)	**33.**	(a, c, d)	**34.**	(c, d)
35.	(b, c)	**36.**	(a, b)	**37.**	(c, d)
38.	(a, b, c, d)	**39.**	(b, d)	**40.**	(a, c)
41.	(a, d)	**42.**	(c, d)	**43.**	(c, d)
44.	(b, c, d)	**45.**	(a, b, c, d)	**46.**	(a, d)

47. (d) $DE = \frac{12400}{4.500 Å}$

$\Delta = 2.75$ eV

For photoelectric effect, $\Delta E > W_0$ (work function).

48. (a) $\Delta E = W_0 + E$; $(E_k) = \Delta E - W_0$

For maximum value of (E_k), W_0 should be minimum

W_0 for lithium = 2.3 eV

$\therefore$ $(E_k) = 2.75 - 2.3 = 0.45$ eV

49. (c) The maximum magnitude of stopping potential will be for metal of least work function.

$\therefore$ required stopping potential is

$$V_s = \frac{h\nu - \phi_0}{e} = 0.45 \text{ volt.}$$

50. (d) Total energy released from $Au^{198} \to Hg^{198}$ in ground state = $(\Delta m_{loss})\,c^2 = (197.9682 - 197.9662)(930) = 1.86$ MeV

Energy released from ^{198}Hg in first excited state → Hg in ground state = (–1.6) – (–2) MeV = 0.4 MeV

⇒ Energy released from $Ag^{198} \to Hg^{198}$ second excited state = 1.86 – 0.4 = 1.46 MeV = max K.E. of β_2 particle.

51. **(d)** Similarly maximum kinetic energy of β_1 particle = 1.86 – 1 = 0.86 MeV

52. **(a)**

53. (b) **54.** (b) **55.** (a) **56.** (a) **57.** (a) **58.** (a)

59. (a)

60. Let at time t, numbers of atoms of the radioctive substance are N.

It may decay either by α-emission or by β-emission.

$$\left(-\frac{dN}{dt}\right)_{net} = \left(-\frac{dN}{dt}\right)_{\alpha} + \left(-\frac{dN}{dt}\right)_{\beta}$$

If, decay constant is λ, then

$$\lambda N = \lambda_\alpha N + \lambda_\beta N$$

$$\lambda = \lambda_\alpha + \lambda_\beta = \frac{1}{1620} + \frac{1}{405} = \frac{1}{324} \text{year}^{-1}$$

As $N = N_0 e^{-\lambda t}$

Here, $N = \frac{N_0}{4}$

$$\therefore -\lambda t = \ell n\left(\frac{1}{4}\right) = -1.386 \qquad \left(\frac{1}{324}\right)t = 1.386$$

t = 449 years

61. (i) Mass defect = $[3 \times m_p + 4 \times m_n] - 7u$

(ii) Binding energy = mass defect × 931.5 MeV

(iii) Binding energy per nucleon = $\frac{\text{Binding energy}}{7}$

62. $E = \Delta mc^2$

63. The equation of decay process is

$$_{92}U^{238} \to {}_{82}Pb^{206} + n(_2He^4) + m(_{-1}\beta^\circ)$$

Here n and m are the numbers of α and β particles respectively. By conservation of mass

$$206 + n(4) = 238$$
$$\therefore \quad n = 8$$
$$\text{Also } 82 + 2n + m(-1) = 92$$
$$\text{or } 82 + 2 \times 8 - m = 92$$
$$\therefore \quad m = 6$$

64. The process can be expressed as :

$$_{72}A^{180} \xrightarrow{\alpha} {}_{70}A_1^{176} \xrightarrow{\beta^-} {}_{71}A_2^{176} \xrightarrow{\alpha} {}_{69}A_3^{172} \xrightarrow{\gamma} {}_{69}A_4^{172}$$

Thus, the mass number of A_4 is 172.

65. If N_0 is the initial level of radiation and N is the permissible level, then

$$N = \frac{N_0}{50}.$$

We know that $N = N_0 e^{-\lambda t}$ ...(1)

where $\lambda = \frac{0.693}{t_{1/2}}$

$$= \frac{0.693}{10} = 0.0693 \text{ day}^{-1}$$

From equation (1), we have

$$\frac{N_0}{50} = N_0 \, e^{-0.0693t}$$

or $t = 56.45$ days

Chapter 9

ELECTRONICS

INTRODUCTION

We watch T.V. in our houses for entertainment, news, sports live etc. We use computers for multi-purposes. We use calculators, electronic watches, digital thermometers, digital glucometers to measure the amount of glucose in our body and so on. There are a number of devices which we use in our day to day life which are based on the subject matter of this chapter. The chapter is all about the branch of physics called electronics. There is no wonder to say that we are living in the age of electronics. It is prevailing in every walk of our life. The most powerful discovery of this branch of physics is the mobile technology which has become an inevitable part of our life. This chapter deals with the components of electronics such as semiconductors, diodes, *p-n* junction, transistor, the logic gates etc. The semiconductor junctions led to the discovery of integrated circuits (I.C.) which have revolutionised the electronic industry.

ENERGY BANDS IN SOLIDS

In an isolated atom, electrons present in energy level but in solid, atoms are not isolated. There is interaction among each other. Due to this, energy level split into different energy levels. Quantity of these different energy levels depends on the quantity of interacting atoms. Splitting of sharp and closely compact energy levels result into energy band. This is discrete in nature. The order of energy levels in a band is 10^{23} and their energy difference = 10^{-23}eV

Let us see the energy bands in sodium.

When the sodium atoms are far apart, all 3s electrons have same energy and as we begin to move them together, the energy levels begin to "split". The situation for four sodium atoms is shown in figure. As the number of atoms is increased (may be 10^{20} atoms), the levels become so numerous and so close that we can no longer distinguish the individual levels as shown in figure. We can regard the N atoms as forming an almost continuous band of energy. Since, those levels were identified with 3s atomic levels of sodium, we refer to the 3s band.

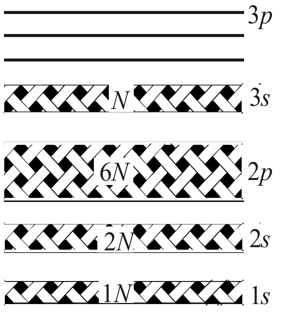


Fig. 9.1- *Energy bands in sodium metal (ground state)*

Each band has a total of N individual levels. Each level can hold $2 \times (2\ell + 1)$ electrons (ℓ is azimuthal quantum number), so the capacity of each band is $2(2\ell + 1)N$ electrons.

Figure shows a complete representation of energy bands in sodium metal. The 1s, 2s and 2p bands are each full, 3s band is half and 3p band is completely empty. The 1s and 2s bands each contain 2N electrons and 2p band contain 6N electrons. The 3s band contain N electron, so it is half filled. The band, which can hold 6N electrons is completely empty.

When we add energy to a system i.e., to sodium metal, the electron can move from filled state to empty state. In this case, the electron can move from partially full states of 3s band to empty states of 3s band by absorbing small amount of energy or move to 3p band by absorbing larger amount of energy.

In a solid at zero temperature, the electron settle into the available states of lowest energy. The lower energy bands will therefore be completely filled and the upper most energy band will be either filled or partially filled, depending on the number of electrons and on the number of available states. The diffence between conductor and insulator arises from a partially filled or a completely filled upper most energy band.

Valence Band and Conduction Band

According to Pauli exclusion principle, each energy level can have two electrons with opposite spins. So normally only lower energy bands are filled with electrons. The highest energy band containing electrons is called **valence band**. This band may be completely or partially filled with electrons. In inert gases, it is completely filled whereas for other material, it is partially filled. The next higher band to valence band is called **conduction band**. All electrons in the conduction band are free electrons. The conduction band is partially filled for conductors and is empty for insulators.

CLASSIFICATION OF SOLIDS-CONDUCTORS, INSULATORS AND SEMICONDUCTORS

If the valence band and the conduction band overlap, the substance is called **conductor.** If the forbidden gap between valence band and conduction band is very large (more than 3 eV), the substance will be **insulator**. In such material a very high electric field is required to push the electron from valance band to conduction band. If the forbidden gap between valence band and conduction band is less than 3 eV, the substance is called **semi-conductor.** Germanium (Ge) and silicon (Si) are the well known semiconductors. In germanium forbidden gap E_g = 0.7 eV and in silicon E_g = 1.1 eV. At 0 K, semiconductor behaves like an insulator.

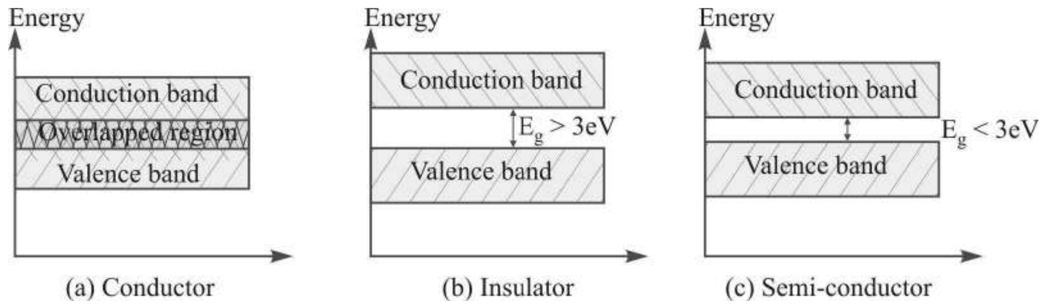


Fig. 9.2

Types of Semiconductor

There are two types of semiconductor.

(i) Intrinsic Semiconductor : These semiconductors are pure materials in which the thermal vibrations of the lattice have liberated charge carriers (i.e., electrons & holes). In intrinsic semiconductor, the number of electrons are equal to the number of holes.

(ii) Extrinsic Semiconductor : They are impure semiconductors in which minutes traces of impurity introduces mobile charge carriers [which may be + ve (holes) or–ve (electrons)] in addition to those liberated by thermal vibration.

Again there are two types of Extrinsic semiconductors (i) N-type semiconductor (ii) P-type semiconductor.

N- type semiconductor

When a pure semiconductor (Si or Ge) is doped by pentavalent impurity (P, As, Sb, Bi) then four electrons out of the five valence electrons of impurity take part, in covalent bonding, with four silicon atoms surrounding it and the fifth electron is set free. These impurity atoms which donate free e^- for conduction are called as Donor impurity (N_D). Here free e^- increases very much so it is called as *n*-type semiconductor. Here impurity ions known as "Immobile Donor positive Ion". Free e^- called as majority charge carriers and holes called as minority charge carriers.

P -type semiconductor

When a pure semiconductor (Si or Ge) is doped by trivalent impurity (B, Al, In, Ga) then outer most three electrons of the valence band of impurity take part, in covalent bonding with four silicon atoms surrounding it and except one electron from semiconductor and make hole in semiconductor. These impurity atoms which accept bonded e^- from valance band are called as Acceptor impurity (N_A). Here holes increases very much so it is called as *p*-type semiconductor here impurity ions known as "Immobile Acceptor negative Ion". Free e^- are called as minority charge carriers and holes are called as majority charge carriers.

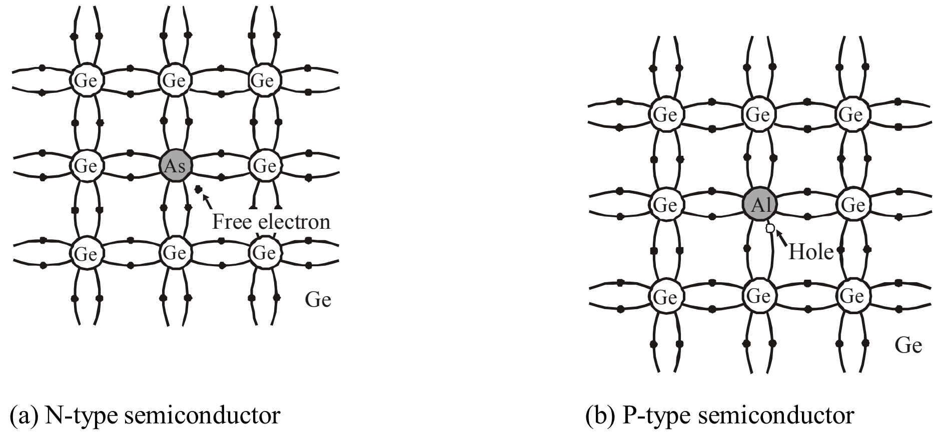
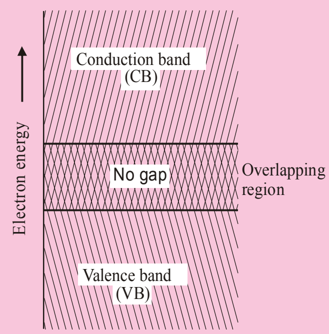
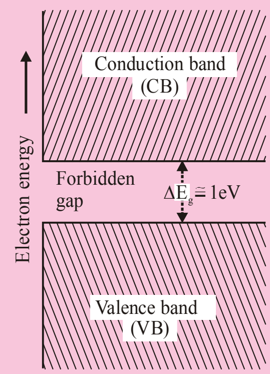
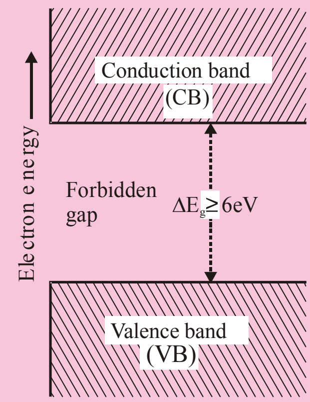


Fig.9.3

Knowledge ENHANCER

Property	Conductors	Semiconductors	Insulators
Resistivity range	$10^{-6} - 10^{-8}\ \Omega m$	$10^{-4} - 0.5\ \Omega m$	$10^{7} - 10^{16}\ \Omega m$
Conductivity range	$10^{-6} - 10^{-8}$ mho/m	$10^{4} - 0.5$ mho/m	$10^{-7} - 10^{-16}$ mho/m
Temp. coefficient of resistance (α)	Positive	Negative	Negative
Flow of current	Due to free electrons	Due to electrons and holes	No current flow
Energy band diagram			
Forbidden energy gap	$\cong$ 0eV	$\cong$ 0.1 – 3eV	$\geq$ 6eV
Examples	Pt, Al, Cu, Ag etc.	Ge, Si, C, Ga, As GaF_2 etc.	Wood, plastic diamond, mica

P-N JUNCTION OR P-N JUNCTION DIODE

When a P-type semiconductor is suitably joined to an N-type semiconductor, then resulting arrangement is called P-N junction or P-N junction diode.

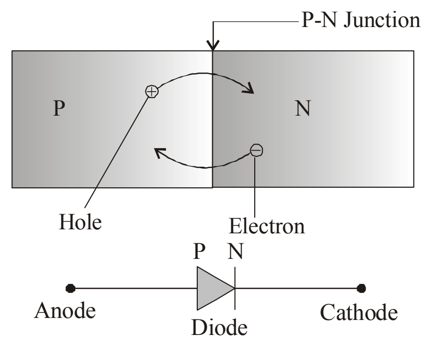


Fig.9.4

Depletion region : On account of difference in concentration of charge carriers in the two sections of P-N junction, the electrons from N-region diffuse through the junction into P- region and the hole from P region diffuse into N-region.
Due to diffusion, neutrality of both N and P-type semiconductor is disturbed. *A layer of negative charged ions appear near the junction in the P-crystal and a layer of positive ions appears near the junction in N-crystal. This layer is called depletion region or layer.*

P-N JUNETION DIODE AS A RECTIFIER

Junction diode (*p-n* junction) can be used to convert the alternating current (a.c.) into direct current (d.c.). *The process of conversion from a.c. to d.c. is known as rectification and the device is called rectifier*. A *p-n* junction can be used as a half wave or full wave rectifier.

Half Wave Rectifier

For half wave rectification we have to use only one P-n junction diode. The arrangement is shown in Figure.

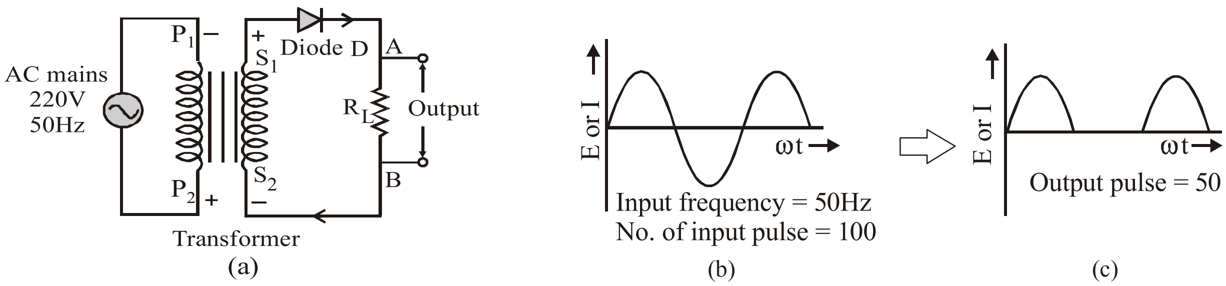


Fig.9.5

During the first half (positive) of the input signal, let S_1 is at positive and S_2 is at negative potential. So, the PN junction diode D is forward biased. The current flows through the load resistance R_L and output voltage is obtained.

During the second half (negative) of the input signal, S_1 and S_2 would be negative and positive respectively. The PN junction diode will be reversed biased. In this case, practically no current would flow through the load resistance. So, there will be no output voltage.

Thus, corresponding to an alternating input signal, we get a unidirectional pulsating output.

Peak voltage (PIV) $V_s = V_{in}$

In half wave rectifier PIV = maximum voltage across secondary coil of transformer.

Full Wave Rectifier

When the diode rectifies the whole of the AC wave, it is called full wave rectifier. For full wave rectification we have to use two diodes. Figure shows the experimental arrangement for using diode as full wave rectifier. The alternating signal is fed to the primary of a transformer. The output signal appears across the load resistance R_L.

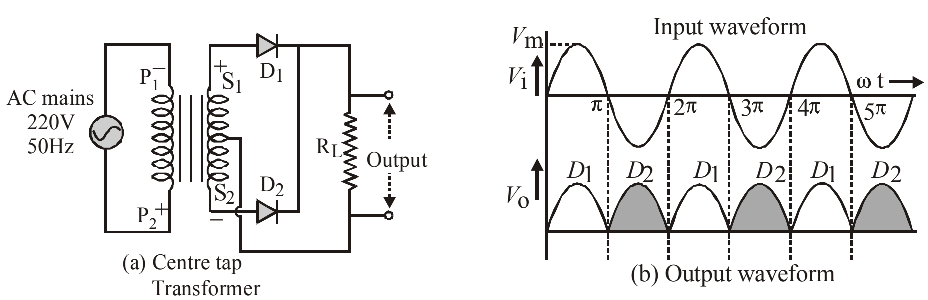


Fig.9.6

During the positive half of the input signal : Let S_1 positive and S_2 negative.

In this case diode D_1 is forward biased and D_2 is reverse biased. So only D_1 conducts and hence the current flows in the load resistance R_L.

During the negative half of the input signal : Now S_1 is negative and S_2 is positive.

So D_1 is reverse-biased and D_2 is forward biased. So only D_2 conducts and hence the current flows through the load resistance R_L.

It is clear that whether the input signal is positive or negative, the current always flows through the load resistance in the same direction and full wave rectification is obtained.

JUNCTION TRANSISTOR

Transistors are three terminal (solid state) devices just like triode. It can be assumed to consist of two back to back *p-n* junctions. In practice a junction transistor (*p-n-p*) consists of silicon (or germanium) bar crystal in which a layer of *n*-type silicon (or Ge) is sandwiched between two layers of *p*-type silicon and we get *p-n-p* transistor. Alternatively, it may consist of a layer of *p*-type between two layers of *n*-type material and we get a *n-p-n* transister as shown by figure.

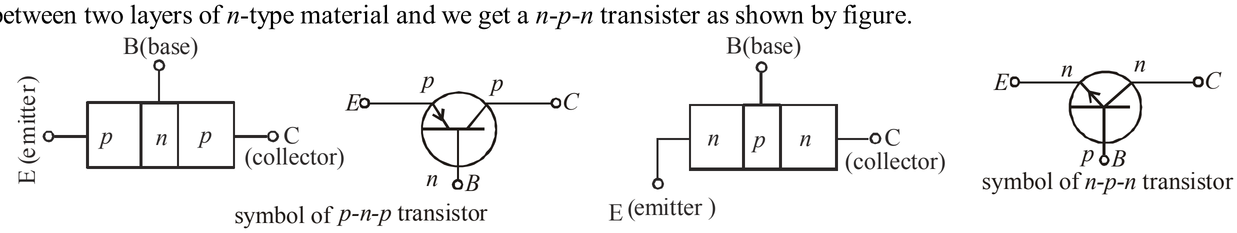


Fig.9.7

Components of Transistor

Emitter (E) : It supplies charge carriers (electron in *n-p-n* transistor and holes in *p-n-p* transistor) and it has high density of impurity concentration i.e., highly doped. It is always forward biased.

Collector (C) : It is a region on other side of base. It has maximum area out of other sections (emitter and base) of transistor to dissipate the heat. It collects the charge carriers and it is always reverse biased.

Base (B) : It is middle region which forms the two junctions between emitter and collector. It is very lightly doped.

CHECK Point

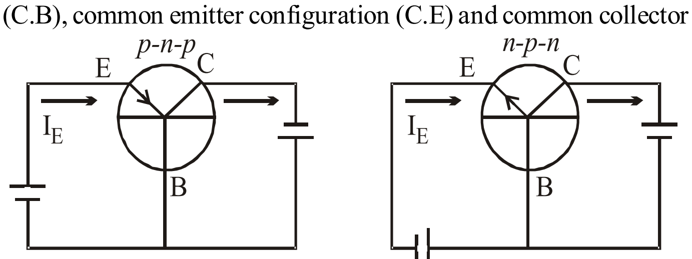
Why is a transistor so called ?

SOLUTION

The word Transistor can be treated as short form of two words 'transfer + resistor'. In a transistor, a signal is introduced in the low resistance circuit and output is taken across the high resistance circuit. Thus, a transistor helps to transfer the current from low resistance part to the high resistance part.

Biasing of Transistor

In proper biasing of transistor the input (i.e., base emitter junction) is always forward biased and output (i.e., collector base junction) is always reverse biased as shown in figure. [This scheme of biasing is same for all three transistor configurations; common base configuration (C.B), common emitter configuration (C.E) and common collector configuration (C.C)]



(a) (b)

Fig.9.8

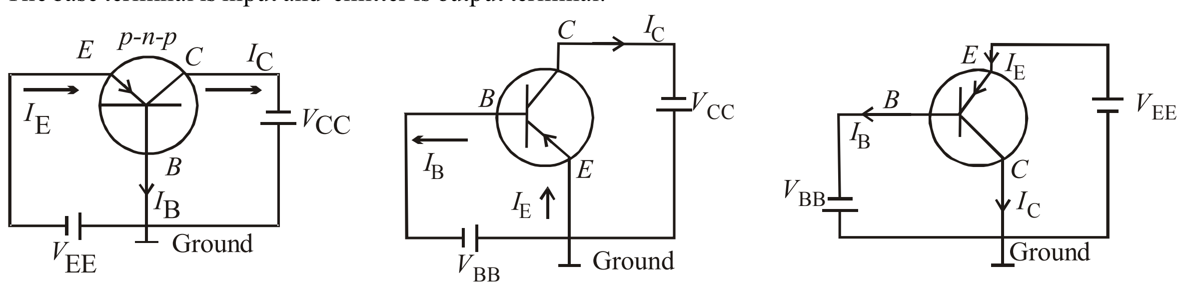
Transistor Configuration

There are three types of transistor configuration. We can take either terminal as input terminal and other terminal as output.

(i) **Common base configuration (C.B.) :** Here base terminal is common to both input and output terminals. The emitter terminal is taken as input.

(ii) **Common emitter configuration (C.E.) :** Here emitter terminal is common to both input and output terminal. The base terminal is taken as input and collector is taken as output.

(iii) **Common collector configuration (C.C.) :** Here the collector terminal is common to both input as well as output terminals. The base terminal is input and emitter is output terminal.



(*a*) *C.B. Configuration* (*b*) *C.E. Configuration* (*c*) *C.C. Configuration*

Fig.9.9

Working of Transistor

Figure shows a common base configuration of *p-n-p* transistor. The forward biasing of emitter junction lowers the emitter base potential barrier height, whereas the reverse biasing of collector junction increases the collector-base potential barrier height. Hence, holes (majority carriers in *p*-type) flows through emitter to base and constitutes an emitter current I_E. Since, emitter is heavily doped in comparison to base, so approximately (only 5% holes recombine with electrons in base region and constitute base current I_B) 95% holes reach to collector and constitute collector current I_C.

From Kirchhoff's current law, $I_E = I_C + I_B$ ...(1)

Equation (1) holds true regardless of circuit configuration or transistor type (*p-n-p* or *n-p-n*) that is used.

The ***current gain*** **(β)** *of transistor is defined as ratio of collector current I_C to base current I_B*

i.e., $\beta = \frac{I_c}{I_B}$ ...(2)

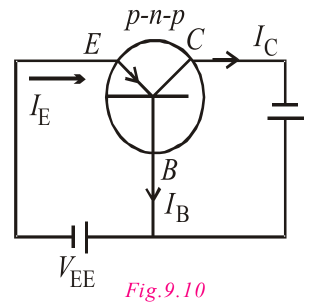


Fig.9.10

The value of β lies between 10 and100.

Since $I_E \approx I_C$ and exactly $I_E = \alpha I_C$ ...(3)

Whereas α *is defined as the ratio of collector current I_C to emitter current I_E*. The value of α is always less than unity. In terms of β

$$\alpha = \frac{\beta}{1+\beta} \quad \Rightarrow \quad \beta = \frac{\alpha}{1-\alpha} \qquad ...(4)$$

CHECK Point

The base region of a transistor is lightly doped. Explain why?

SOLUTION

In a transistor, the majority carriers (holes or electrons) from emitter region move towards the collector region through base. If base is made thick and highly doped, then majority of carriers from emitter will combine with the carriers in the base and only small number of carriers will reach the collector. Thus the output or collector current will be considerably small. To get large output or collector current, base is made thin and lightly doped so that only few electron-hole combination may take place in the base region.

TRANSISTOR AS AN AMPLIFIER

Amplification is the process of linearly increasing the amplitude of a signal and is one of the major properties of a transistor. This amplifing action was produced by transfering a current from a low (base emitter loop in forward biased and hence provide low resistance path and collector base junction is reverse biased and hence gives high resistance path in common emitter configuration) to a high resistance circuit.

Common-Emitter Amplifier

Figure shows a p–n–p transistor as an amplifier in common emitter mode. The emitter is common to both input and output circuits. The input (base-emitter) circuit is forward biased by a low voltage battery V_{BE}. The output (collector-emitter) circuit is reverse bised by means of a high voltage battery V_{CC}. Since, the base-emitter circuit is forward biased, input resistance is low. Similarly, collector-emitter circuit is reverse biased, therfore output resistance is high. The weak input AC signal is superimposed on V_{BE} and the amplified output signal is obtained across the collector-emitter circuit.

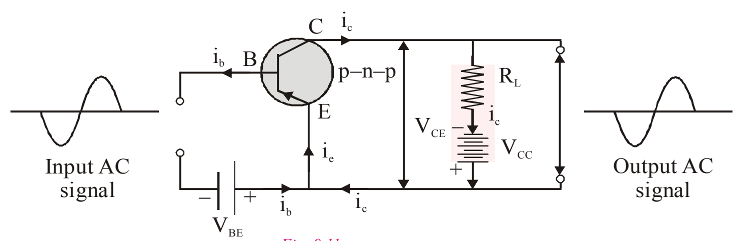


Fig. 9.11

In the figure we can see that,

$$V_{CE} = V_{CC} - i_c R_L$$

When the input AC voltage signal is applied across the base-emitter circuit, it fluctuates V_{BE} and hence the emitter current i_e. this in turn changes the collector current i_c consequently V_{CE} varies in accordance with the above equation. This variation in V_{CE} appears as an amplified output.

CURRENT GAIN, VOLTAGE GAIN, POWER GAIN AND TRANSCONDUCTANCE

(i) Current gain : Also called ac current gain (β_{ac}), is defined as the ratio of the collector current to the base current at constant collector to emitter voltage.

$$\beta_{ac} \text{ or simply } \beta = \frac{\Delta i_c}{\Delta i_b} \quad (V_{CE} = \text{constant})$$

(ii) Voltage gain : It is defined as the ratio of the change in the output voltage to the change in the input voltage. It is denoted by A_V. Thus,

$$A_V = \frac{\Delta i_c \times R_{out}}{\Delta i_b \times R_{in}} \quad \text{or} \quad A_V = \beta \frac{R_{out}}{R_{in}}$$

(iii) Power gain : It is defined as the ratio of change in output power to the change in the input power. Since, $P = Vi$

Therefore, power gain = current gain × voltage gain

or $$\text{Power gain} = \beta^2 \frac{R_{out}}{R_{in}}$$

(iv) Transconductance: It is the ratio of the change in the collector current to the change in the base to emitter voltage at constant collector to emitter voltage.

i.e. Transconductance $g_m = \left(\frac{\Delta i_c}{\Delta V_{BE}}\right) = \frac{\beta}{R_{in}}$ [V_{CE} = constant]

ILLUSTRATION : 1

For a transistor, the current amplification factor is 0.8, the transistor is connected in common emitter configuration. Find the change in the collector current when the base current changes by 6 mA.

SOLUTION

Given: $a = 0.8$; $\Delta I_b = 6\text{mA}$; $\Delta I_c = ?$

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.8}{1-0.8} = 4 ; \quad \beta = \Delta I_c / \Delta I_b \text{ or } \Delta I_c = \beta \Delta I_b = 4 \times 6 = 24\,mA$$

Illustration : 2

The current gain of a transistor in a common emitter configuration is 40. If the emitter current is 8.2 mA, then find base current.

SOLUTION

As we know, $\beta = \frac{I_c}{I_b} = \frac{I_e - I_b}{I_b} = \frac{I_e}{I_b} - 1$ or $\frac{I_e}{I_b} = 1 + \beta$

or $I_b = \frac{I_e}{1+\beta} = \frac{8.2}{1+40} = \frac{8.2}{41} = 0.20\,mA$

ILLUSTRATION : 3

In a common emitter transistor amplifier $\beta = 60$, $R_0 = 5000\,\Omega$ and internal resistance of a trnasistor is 500 Ω. Find the voltage amplification of amplifier.

SOLUTION

As we know, voltage amplification $A_v = \beta \frac{R_0}{R_i} = 60 \times \frac{5000}{500} = 600$

Illustration : 4

In a n-p-n transistor 10^{10} electrons enter the emitter in 10^{-6} s. 4% of the elctrons are lost in the base. What will be the current transfer ratio.

SOLUTION

No. of electrons reaching the collector, $n_c = \frac{96}{100} \times 10^{10} = 0.96 \times 10^{10}$

Emitter current, $I_e = \frac{n_e \times e}{t}$; Collector current, $I_c = \frac{n_c \times e}{t}$

$\therefore$ Current transfer ratio, $a = \frac{I_c}{I_e} = \frac{n_c}{n_e} = \frac{0.96 \times 10^{10}}{10^{10}} = 0.96$

CHECK Point

Explain why the emitter is forward biased and the collector is reverse biased in a transistor ?

SOLUTION

In a transistor, the charge carriers move from emitter to collector. The emitter sends the charge carriers and collector collects them. This can happen only if emitter is forward biased and the collector is reverse biased so that it may attract the carriers.

Logic Gate

A logic gate is a digital circuit which is based on certain logical relationship between the input and the output voltage of the circuit.

- The logic gates are built using the semiconductor diodes and transistors.
- Each logic gate is represented by its characteristic symbol.
- The operation of a logic gate is indicated in a table, known as truth table. This table contains all possible combinations of inputs and the corresponding outputs.
- A logic gate is also represented by a Boolean algebraic expression. Boolean algebra is a method of writing logical equations showing how an output depends upon the combination of inputs. Boolean algebra was invented by George Boole.

Basic Logic Gates

There are three basic logic gates.
They are (a) *OR gate* (b) *AND gate*, and (c) *NOT gate*.

(a) OR gate :

Symbol of OR gate

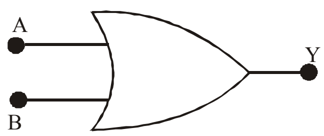


Fig. 9.12

Truth table

Input		Output
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

Boolean algebraic expression : $Y = A + B$

(b) AND gate :

Symbol of AND gate

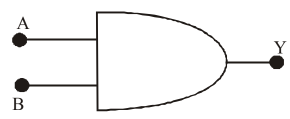


Fig. 9.13

Truth table

Input		Output
A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

Boolean algebraic expression : $A \cdot B = Y$

(e) NOT gate:

Symbol of NOT gate

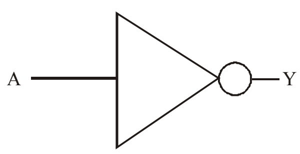


Fig. 9.14

Truth table

Input	Output
A	Y
0	1
1	0

Boolean algebraic expression : $Y = \overline{A}$

Combination of Logic Gates

(a) NAND gate : It is the combination of AND and NOT gate

Symbol of NAND gate

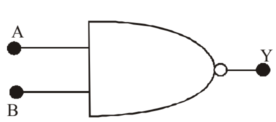


Fig.9.15

Truth table

Input		Output
A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

Boolean algebraic expression : $Y = \overline{A \cdot B}$

(b) NOR gate : It is the combination of NOT and OR gate

Symbol of NOR gate

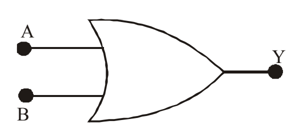


Fig. 9.16

Truth table

Input		Output
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

Boolean algebraic expression : $Y = \overline{A + B}$

(c) Exclusive OR gate (XOR gate) :

Symbol of XOR gate

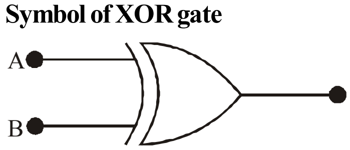


Fig. 9.17

Truth table for XOR gate

A	B	$Y = A\overline{B} + \overline{A}B$
0	0	0
0	1	1
1	0	1
1	1	0

Boolean algebraic expression: $Y = A\overline{B} + \overline{A}B$

Note : The NAND gate is the universal building block of all digital circuits. Repeated use of NAND gate or NOR gate gives other gates. Therefore, any digital system can be achieved entirely from NAND or NOR gate.

(i) NOT gate from NAND gate :

Figure

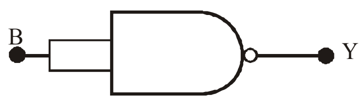


Fig. 9.18

Truth table

B	B	$Y=\overline{B\cdot B}$
0	0	1
1	1	0

(ii) AND gate from NAND gate :

Figure

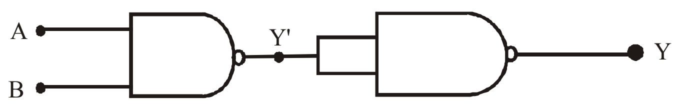


Fig. 9.19

Truth table

A	B	$\overline{A\cdot B}=Y'$	$Y=\overline{Y'}$
0	0	1	0
0	1	1	0
1	0	1	0
1	1	0	1

(iii) OR gate from NAND gate :

Figure

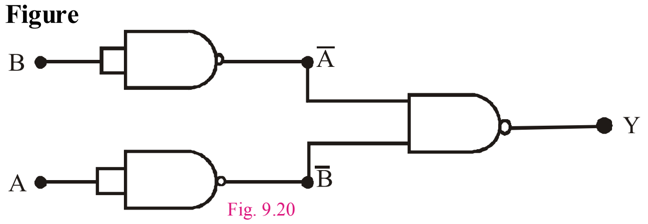


Fig. 9.20

Truth table

A	B	$\overline{A}$	$\overline{B}$	$Y=(\overline{\overline{A}\cdot\overline{B}})$
0	0	1	1	0
0	1	1	0	1
1	0	0	1	1
1	1	0	0	1

BINARY NUMBERS AND DECIMAL NUMBERS

- In a binary system, a number is expressed by only two digits 0 and 1. The base of the binary system is thus 2.
- 0 and 1 represent the coefficients of powers of 2.
- A binary digit (0 or 1) is known as a bit.
- A group of 4 bit is called a **nibble** and a group of 8 bit is called **byte**.
- In a decimal number system, we have ten digits i.e., 0, 1, 2, 3, 4, 5, 6, 7, 8, 9. The base of decimal system is 10.

Different names for the digital signals

State code	1	0
Name of the state	On	Off
	Up	Down
	Close	Open
	Excited	Unexcited
	True	False
	Pulse	No pulse
	High	Low
	Yes	No

Decimal to Binary Conversion

1. When the decimal number is an integer : Divide the decimal number progressively by 2 until the quotient is zero. The remainders of the successive divisions, written in the reverse order, give the binary number.

For example: We want to convert $(9)_{10}$ into binary system.

$\frac{9}{2}$ $1 \rightarrow$ first remainder

$\frac{4}{2}$ $0 \rightarrow$ second remainder ($\uparrow$Read up)

$\frac{1}{0}$ $0 \rightarrow$ third remainder

$1 \rightarrow$ fourth remainder

So, $(9)_{10} = (1001)_2$

2. **When the decimal number is a fraction :** The number is multiplied repeatedly by 2, and the carry in the integer position is recorded each time. The process is continued until the fractional part is zero or sufficient binary bits have been obtained.
For example: We want to convert $(0.85)_{10}$ into binary number
$0.85 \times 2 = 1.7 = 0.7$ with a carry 1
$0.7 \times 2 = 1.4 = 0.4$ with a carry 1
$0.4 \times 2 = .8 = 0.8$ with a carry 0 (↓ Read down)
$0.8 \times 2 = 1.6 = 0.6$ with a carry 1
$0.6 \times 2 = 1.2 = 0.2$ with a carry 1
$0.2 \times 2 = .4 = 0.4$ with a carry 0
So, $(0.85)_{10} = (0.110110)_2$

Binary to Decimal Conversion

1. **When the binary number is an integer :** Binary can be converted into its decimal equivalent by noting that the successive digits from the extreme right of a binary number are the coefficients of ascending power of 2, beginning with the zeroth power of 2 at the extreme right.
For example: $(111111100101)_2 = 1 \times 2^{10} + 1 \times 2^9 + 1 \times 2^8 + 1 \times 2^7 + 1 \times 2^6 + 1 \times 2^5 + 0 \times 2^4 + 0 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 = 2021$
2. **When the binary number is a fraction :** The decimal equivalent of the binary number is found by multiplying each digit in fraction sucessively by 2^{-1}, 2^{-2}, 2^{-3}...etc.
For example: We want to convert $(101.011)_2$ into its decimal equivalent.
$(101.011)_2 = 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 + 0 \times 2^{-1} + 1 \times 2^{-2} + 1 \times 2^{-3} = (5.375)_{10}$
$5.375 = 5 \times 10^0 + 3 \times 10^{-1} + 7 \times 10^{-2} + 5 \times 10^{-3}$

LAWS OF BOOLEAN ALGEBRA AND DE-MORGAN'S THEOREM

Basic OR, AND, and NOT operations are given below:

OR	*AND*	*NOT*
$A + 0 = A$	$A \cdot 0 = 0$	$A + \overline{A} = 1$
$A + 1 = 1$	$A \cdot 1 = A$	$A \cdot \overline{A} = 0$
$A + A = A$	$A \cdot A = A$	$\overline{\overline{A}} \cdot A = A$

Boolean algebra obeys commutative, associative and distributive law as given below :

Commutative laws :
A + B = B + A
A . B = B .A

Associative laws :
A + (B + C) = (A + B) + C
A . (B . C) = (A . B) . C

Distributive laws :
A . (B + C) = A.B + A.C

Some other useful identities :
(i) A + AB = A
(ii) A . (A + B) = A
(iii) $A + (\overline{A}B) = A + B$
(iv) $A \cdot (\overline{A} + B) = A \cdot B$
(v) A + (B . C) = (A + B). (A + C)
(vi) $(\overline{A} + B).(A + C) = \overline{A}.C + B.A + B.C$

De Morgan's Theorem :

First theorem : $\overline{A + B} = \overline{A}.\overline{B}$

Second theorem : $\overline{A.B} = \overline{A} + \overline{B}$

ILLUSTRATION : 5

Construct the truth table for the function X of A and B represented by figure shown here.

Fig. 9.21

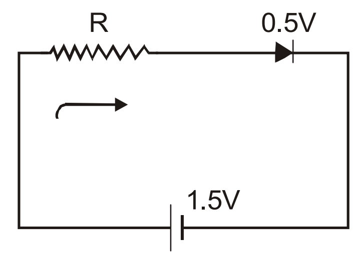
Sol. The output X in terms of the input A and B can be written as, X = A. (A + B)
Let us make the truth table corresponding to this function.

Table

A	**B**	**A + B**	**X = A. (A + B)**
0	0	0	0
0	1	1	0
1	0	1	1
1	1	1	1

MISCELLANEOUS SOLVED EXAMPLES

1. The diode used in the circuit shown has a constant voltage drop at 0.5 V at all currents and a maximum power rating of 100 milli-watts. What should be the value of the resistor R, connected in series with diode and obtaining maximum current?



Sol. Given : $V_P = 0.5$ V, maximum power rating $P = 100$ mW $= 100 \times 10^{-3}$ W and source voltage $V_s = 1.5$ V.

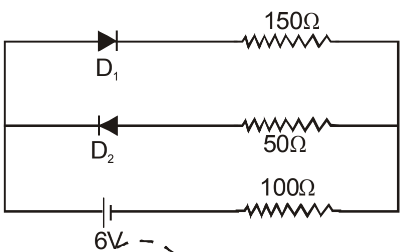
Now diode resistance $R_D = \dfrac{V_P^2}{P} = \dfrac{(0.5)^2}{100 \times 10^{-3}} = 2.5\,\Omega$

Current in diode $I_D = \dfrac{V_D}{R_D} = \dfrac{0.5}{2.5} = 0.2\text{A}$

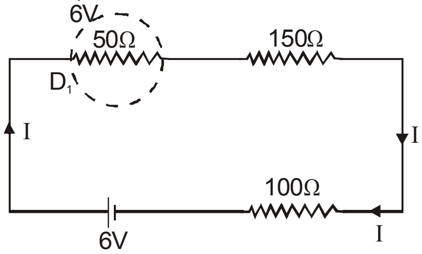
$\therefore$ Total resistance in the circuit $R_T = \dfrac{V_s}{I_D} = \dfrac{1.5}{0.2} = 7.5\,\Omega$

So, resistance R in circuit $= R_T - R_D = 7.5 - 2.5 = 5\,\Omega$

2. The circuit shown in fig. contains two diodes each with a forward resistance of 50Ω and with infinite reverse resistance. If the battery voltage is 6 V, find the current through the 100Ω resistance.



Sol. In this circuit, diode D_1 is forward biased and offers a resistance of 50Ω. The diode D_2 is reverse biased and offers infinite resistance to the current i.e. no current flows through D_2. Thus the equivalent circuit is as shown in fig.



Total resistance of circuit $= 50 + 150 + 100 = 300\Omega$

Current through 100Ω, $I = \dfrac{V}{R} = \dfrac{6}{300} = 0.02\text{ A}$.

3. A p-n-p transistor is used in common-emitter mode in an amplifier circuit. A change of 40 μA in the base current brings a change of 2 mA in collector current and 0.04 V in base emitter voltage. Find the (i) input resistance R_i (ii) the base current amplification factor (β) (iii) If a load resistance of 6 kΩ is used, then also find the voltage gain of the amplifier.

Sol. Here, $\Delta I_b = 40 \times 10^{-6}\text{A}$; $\Delta I_c = 2 \times 10^{-3}\text{A}$;

(i) Input resistance, $R_i = \dfrac{\Delta V_i}{\Delta I_b} = \dfrac{0.04}{40 \times 10^{-6}} = 10^3\,\Omega$

(ii) Base current amplification factor, $\beta = \dfrac{\Delta I_c}{\Delta I_b} = \dfrac{2 \times 10^{-3}}{40 \times 10^{-6}} = 50$

(iii) Voltage gain, $Av = \beta \dfrac{R_0}{R_i} = 50 \times \dfrac{6000}{10^3} = 300$

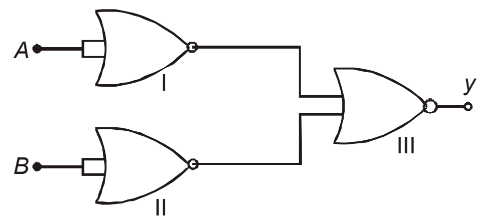
$\Delta V_i = 0.04\text{ V}$; $R_0 = 6000\Omega$

4. In the binary number system 100 + 1011 is equal to

(a) 1000 **(b) 1011** **(c) 1110** **(d) 1111**

Sol. (d) $(100)_2 + (1011)_2 = (0 \times 2^0 + 0 \times 2^1 + 1 \times 2^2) + (1 \times 2^0 + 1 \times 2^1 + 0 \times 2^2 + 1 \times 2^3)$
$= (0 + 0 + 4) + (1 + 2 + 0 + 8) = (15)_{10} = (1111)_2$ or $0100 + 1011 = 1111$

5. Identify the gate represented by the block diagram of fig. Write the Boolean expression and truth table.



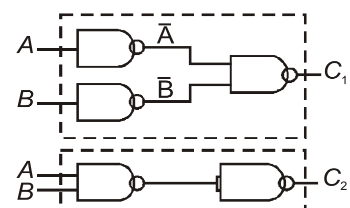
Sol. Here for the input, the two NOR gates have been used as NOT gates (by joining the input terminals of NOR gate). Their outputs are jointly fed to the NOR gate. From the NOR gate I, for the input A, the output is $\overline{A}$. From the NOR gate II, for the input B, the output is $\overline{B}$. From NOR gate III, the output is given by $Y = \overline{\overline{A} + \overline{B}} = A.B$

Thus, Boolean expression for this combination of gate is $Y = \overline{\overline{A} + \overline{B}} = A.B$ ·

Thus, the combination will work as AND gate. The truth table of the combination of gates is

A	B	$\overline{A}$	$\overline{B}$	Y
0	0	1	1	0
1	0	0	1	0
0	1	1	0	0
1	1	0	0	1

6. The combinations of the 'NAND' gates shown here in fig. are equivalent to



(a) an 'OR' gate and an 'AND' gate respectively
(b) an 'AND' gate and a 'NOT' gate respectively
(c) an 'AND' gate and an 'OR' gate respectively
(d) an 'OR' gate and a 'NOT' gate respectively

Sol. (a) For first case, $C_1 = \overline{\overline{A}.\overline{B}} = (A + B)$ (by Demorgan's theorem)

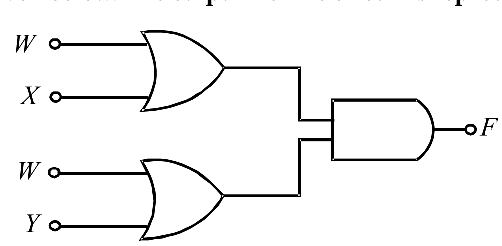
The truth table is shown below

A	B	$\overline{A}$	$\overline{B}$	$\overline{A}.\overline{B}$	$\overline{\overline{A}.\overline{B}}$
1	0	0	1	0	1
0	1	1	0	0	1
0	0	1	1	1	0
1	1	0	0	0	1

This is truth table for $C_1 = A + B$ i.e., OR gate

For second case, $C_2 = \overline{\overline{A.B}} = A.B$ i.e., AND gate.

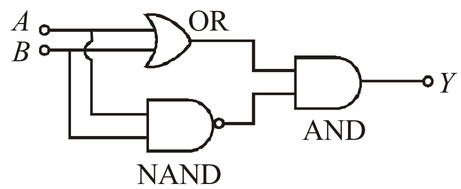
7. The diagram of a logic circuit is given below. The output F of the circuit is represented by



(a) $W.(X+Y)$ **(b)** $W.(X.Y)$ **(c)** $W+(X.Y)$ **(d)** $W+(X+Y)$

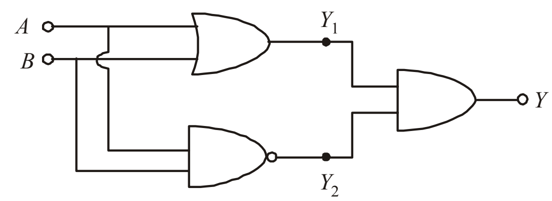
Sol. (c) $(W+X).(W+Y) = W + (X.Y)$

8. The following configuration of gate is equivalent to



(a) NAND gate **(b) XOR gate** **(c) OR gate** **(d) NOR gate**

Sol. (b) $Y_1 = A + B,\ Y_2 = \overline{A.B}$

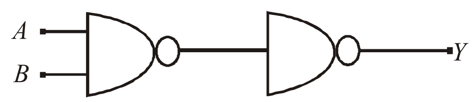


$Y = (A+B)\bullet\overline{AB} = A\bullet\overline{A} + A\bullet\overline{B} + B\bullet\overline{A} + B\bullet\overline{B}$

$= 0 + A\bullet\overline{B} + B\bullet\overline{A} + 0 = A\bullet\overline{B} + B\bullet\overline{A}$

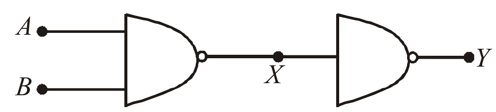
This expression is for XOR

9. Following diagram performs the logic function of



(a) XOR gate **(b) AND gate** **(c) NAND gate** **(d) OR gate**

Sol. (b) $X = \overline{AB}$



$\therefore Y = \overline{X} = \overline{\overline{AB}}$

$Y = AB$ by Demorgan theorem

$\therefore$ This diagram performs the function of AND gate.

EXERCISE

DIRECTIONS (Qs. 1-48) : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. *p-n* junction is said to be forward biased, when
(a) the positive pole of the battery is joined to the *p*-semiconductor and negative pole to the n-semiconductor
(b) the positive pole of the battery is joined to the *n*-semiconductor and p-semiconductor
(c) the positive pole of the battery is connected to *n*- semiconductor and p- semiconductor
(d) a mechanical force is applied in the forward direction

2. At absolute zero, Si acts as
(a) non-metal (b) metal
(c) insulator (d) none of these

3. When *n*-type semiconductor is heated
(a) number of electrons increases while that of holes decreases
(b) number of holes increases while that of electrons decreases
(c) number of electrons and holes remain same
(d) number of electrons and holes increases equally.

4. The following truth table corresponds to the logic gate

A	B	X
0	0	0
0	1	1
1	0	1
1	1	1

(a) NAND (b) OR
(c) AND (d) XOR

5. To use a transistor as an amplifier
(a) the emitter base junction is forward biased and the base collector junction is reverse biased
(b) no bias voltage is required
(c) both junctions are forward biased
(d) both junctions are reverse biased.

6. For amplification by a triode, the signal to be amplified is given to
(a) the cathode (b) the grid
(c) the glass-envelope (d) the anode

7. The part of the transistor which is heavily doped to produce large number of majority carriers is
(a) emitter
(b) base
(c) collector
(d) any of the above depending upon the nature of transistor

8. When a *p-n* junction diode is reverse biased the flow of current across the junction is mainly due to
(a) diffusion of charges
(b) drift of charges
(c) depends on the nature of material
(d) both drift and diffusion of charges

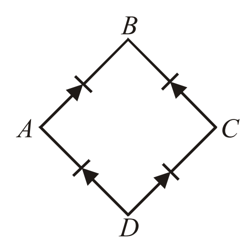
9. What is the value of $A + \overline{A}$ in the Boolean algebra ?
(a) 0 (b) 1
(c) A (d) $\overline{A}$

10. Which of the following gates corresponds to the truth table given below?

A	B	Y
1	1	0
1	0	1
0	1	1
0	0	1

(a) NAND (b) OR
(c) AND (d) XOR

11. In the diagram, the input is across the terminals A and C and the output is across B and D. Then the output is



(a) zero (b) same as the input
(c) full wave rectifier (d) half-wave rectifier

12. Which of the following, when added as an impurity, into the silicon, produces *n*-type semi-conductor?
(a) Phosphorous (b) Aluminium
(c) Magnesium (d) Both b and c

13. When an *n–p–n* transistor is used as an amplifier then
(a) the electrons flow from emitter to collector
(b) the holes flow from emitter to collector
(c) the electrons flow from collector to emitter
(d) the electrons flow from battery to emitter

14. When arsenic is added as an impurity to silicon, the resulting material is
(a) *n*-type semiconductor
(b) *p*-type semiconductor
(c) *n*-type conductor
(d) insulator

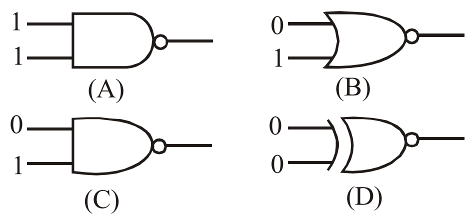
15. To obtain a *p*-type semiconductor, germanium should be doped with
(a) arsenic (b) antimony
(c) indium (d) phosphorus

16. The following truth table belongs to which of the following four gates?

A	B	Y
1	1	0
1	0	0
0	1	0
0	0	1

(a) NOR (b) XOR
(c) NAND (d) OR

17. Which of the following gates will have an output of 1?



(a) D (b) A
(c) B (d) C

18. A gate has the following truth table.The gate is

A	**B**	**Y**
1	1	1
1	0	0
0	1	0
0	0	0

(a) AND (b) NOR
(c) OR (d) NAND

19. The intrinsic semiconductor becomes an insulator at
(a) 0^{o}C (b) 0 K
(c) 300 K (d) -100^{o}C

20. In a *p-n* junction
(a) the potential of the *p* and *n*-sides becomes higher alternately
(b) the *p*-side is at higher electrical potential than the *n*-side
(c) the *n*-side is at higher electrical potential than the *p*-side
(d) Both the *p* and *n*-sides are at the same potential

21. An *n-p-n* transistor conducts when
(a) both collector and emitter are negative with respect to the base
(b) both collector and emitter are positive with respect to the base
(c) collector is positive and emitter is negative with respect to the base
(d) collector is positive and emitter is at same potential as the base

22. Barrier potential of a *p-n* junction diode does not depend on
(a) doping density (b) diode design
(c) temperature (d) forward bias

23. Reverse bias applied to a junction diode
(a) increases the minority carrier current
(b) lowers the potential barrier
(c) raises the potential barrier
(d) increases the majority carrier current

24. In semiconductors, at room temperature
(a) the conduction band is completely empty
(b) the valence band is partially empty and the conduction band is partially filled
(c) the valence band is completely filled and the conduction band is partially filled
(d) the valence band is completely filled

25. The output of OR gate is 1
(a) if either input is zero
(b) if both inputs are zero
(c) if either or both inputs are 1
(d) only if both inputs are 1

26. Application of a forward bias to a *p–n* junction
(a) widens the depletion zone.
(b) increases the potential difference across the depletion zone.
(c) increases the number of donors on the n side.
(d) increases the electric field in the depletion zone.

27. When the temperature of a semiconductor is increased, its electrical conductivity
(a) increases
(b) decreases
(c) remains the same
(d) increases at first and then decreases

28. A piece of copper and another of germanium are cooled from room temperature to 80 K. The resistance of
(a) each of them increases
(b) each of them decreases
(c) copper increases and germanium decreases
(d) copper decreases and germanium increases

29. At absolute zero temperature, a crystal of pure germanium.
(a) behaves as perfect conductor
(b) behaves as perfect insulator
(c) contains no electron
(d) none of the above

30. In an intrinsic semiconductor
(a) only electrons are responsible for flow of current
(b) both holes and electrons carry current
(c) both holes and electrons carry current with electrons being majority carriers
(d) only holes are responsible for flow of current

31. An increase in temperature increases the conductivity of
(a) conductor (b) semiconductor
(c) insulator (d) alloy

32. If the conductivity of a semiconductor is only due to break up of the covalent bonds due to thermal excitation, then the semiconductor is called
(a) intrinsic (b) extrinsic
(c) donor (d) acceptor

33. In a good conductor the number of electrons in the valence shell, in general, is
(a) less than 4 (b) more than 4
(c) equal to 4 (d) none of these

34. The mobility of conduction electrons is greater than that of holes, since electrons
(a) are lighter (b) are negatively charged
(c) require smaller energy for moving through crystal lattice
(d) undergo smaller number of collisions

35. The majority of current carriers in an n-type semiconductor are
(a) holes (b) electrons
(c) negative ions (d) positive ions

36. A hole in p-type semiconductor is
(a) an excess electron (b) a missing electron
(c) a missing atom (d) a donor level

37. An n-type semiconductor is
(a) negatively charged
(b) positively charged
(c) neutral
(d) negatively or positively charged depending upon the amount of impurity

38. A hole in a semiconductor
(a) has zero mass
(b) has mass equal to that of proton
(c) has mass equal to that of positron
(d) is a positively charged vacancy

39. The conductivity of a pure semiconductor can be increased by
(a) increasing temperature
(b) mixing trivalent impurity
(c) mixing pentavalent impurity
(d) all of the above

40. In p-type semiconductor the majority and minority charge carriers are respectively
(a) protons and electrons
(b) electrons and protons
(c) electrons and holes
(d) holes and electrons

41. When boron is added as an impurity to silicon , the resulting material is
(a) n-type semiconductor (b) n-type conductor
(c) p-type conductor (e) p-type semiconductor

42. The depletion layer in the p-n junction is caused by
(a) drift of holes
(b) diffusion of charge carriers
(c) migration of impurity ions
(d) drift of electrons

43. The doping of the base of a transistor is
(a) equal to that of emitter or collector
(b) slightly more than that of emitter or collector
(c) less than that of emiiter or collector
(d) much more than that of emitter or collector

44. In the symbol of a transistor , the arrow head points in the direction of flow of
(a) holes (b) electrons
(c) majority carriers (d) minority carriers

45. In a transistor
(a) emitter is more highly doped than collector
(b) collector is more highly doped than emitter
(c) both are equally doped
(d) none of the above

46. In a transistor
(a) length of emitter is greater than that of collector
(b) length of collector is greater than that of emiter
(c) length of base is greater than that of emitter
(d) length of base is greater than that of collector

47. One way in which the operation of an n-p-n transistor differs from that of a p-n-p is
(a) the emitter junction is reverse biased in n-p-n.
(b) the emitter junction injects minority carriers into base region of the p-n-p is
(c) the emitter injects holes into the base of the p-n-p and electrons into the base region n-p-n
(d) the emitter injects holes into the base of n-p-n

48. n-p-n transistors are preferred to p-n-p transistors because
(a) they have low cost
(b) they have low dissipation energy
(c) they are capable of handling large power
(d) electrons have high mobility than holes and hence high mobility of energy

DIRECTIONS (Qs. 49-53) : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

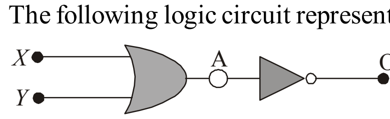
49. Holes are charge carriers in
(a) intrinsic semiconductors
(b) ionic solids
(c) p-type semiconductors
(d) metals

50. Which of the following statements concerning the depletion zone of an unbiased PN junction is (are) true
(a) the width of the zone is independent of the densities of the dopants (impurities)
(b) the width of the zone is dependent on the densities of the dopants
(c) the electric field in the zone is produced by the ionized dopant atoms
(d) the electric field in the zone is provided by the electrons in the conductor band and the holes in the valence band

51. A transistor is used in common emitter mode as an amplifier. Then
(a) the base-emitter junction is forward biased
(b) the base-emitter junction is reverse biased
(c) the input signal is connected in series with the voltage applied to the base-emitter junction
(d) the input signal is connected in series with the voltage applied to bias the base collector junction

52. When a potential difference is applied across, the current passing through
(a) an insulator at 0K is zero
(b) a semiconductor at 0K is zero
(c) a metal at 0K is finite
(d) a P-N diode at 300K is finite, if it is reverse biased

53. The following logic circuit represents



(a) NAND gate with output $O = \overline{X} + \overline{Y}$
(b) NOR gate with output $O = \overline{X + Y}$
(c) NAND gate with output $O = \overline{XY}$
(d) NOR gate with output $O = \overline{X}.\overline{Y}$

DIRECTIONS (Qs. 54-55): *Study the given passage and answer the following questions.*

Passage

In the study of transistor as an amplifier, if $\alpha = I_c/I_e$ and $\beta = I_c/I_b$, where I_c, I_b and I_e are the collector, base and emitter curents, then

54. What is the correct relation between α and β ?

(a) $\beta = \frac{1-\alpha}{\alpha}$ (b) $\beta = \frac{\alpha}{1-\alpha}$

(c) $\beta = \frac{\alpha}{1+\alpha}$ (d) $\beta = \frac{1+\alpha}{\alpha}$

55. For a transistor, in a common emitter arrangement, the alternating curent gain β is given by,

(a) $\beta = \left(\frac{\Delta I_c}{\Delta I_B}\right)_{VC}$ (b) $\beta = \left(\frac{\Delta I_B}{\Delta Ic}\right)_{VC}$

(c) $\beta = \left(\frac{\Delta I_C}{\Delta I_E}\right)_{VC}$ (d) $\beta = \left(\frac{\Delta I_E}{\Delta I_C}\right)_{VC}$

DIRECTIONS (Qs. 56-59): *Each of these questions contains an Assertion followed by reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.

(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.

(c) If **Assertion** is **correct** but **Reason** is **incorrect**.

(d) If **Assertion** is **incorrect** but **Reason** is **correct**.

56. **Assertion :** NAND or NOR gates are called digital building blocks.
Reason : The repeated use of NAND (or NOR) gates can produce all the basis or complicated gates.

57. **Assertion :** When two semi conductor of *p* and *n* type are brought in contact, they form *p-n* junction which act like a rectifier.
Reason : A rectifier is used to convent alternating current into direct current.

58. **Assertion :** NOT gate is also called inverter circuit.
Reason : NOT gate inverts the input order.

59. **Assertion:** In common base configuration, the current gain of the transistor is less than unity.
Reason: The collector terminal is reverse biased for amplification.

DIRECTIONS (Q. 60) : *Following question has four statements (A, B, C and D) given in Column I and 4 statements (p, q, r, s) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

60. Match column I and column II.

Column I	Column II
(A) *p-n* junction is forward biased	(p) Low voltage battery used
(B) *p-n* junction is reverse biased	(q) High voltage battery is used
(C) In *n-p-n* transistor emitter-base junction is forward biasesd.	(r) The conduction across the junction is due to electrons.
(D) In *p-n-p* transistor collector-base junction is reverse biased.	(s) The conduction across the junction is due to holes.

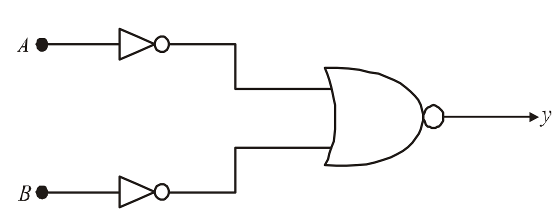
	A	B	C	D
(a)	r, p	p	q, r	q, s
(b)	s	p	q	r, t
(c)	p,r, s	q, r	p, r	p, s
(d)	s	q,r	p, r	s

DIRECTIONS (Qs. 61-64) : *Following are integer based/ Numeric based questions. Each question, when worked out will result in one integer or numeric value.*

61. Frequency of input voltage of a half-wave rectfier is 50 Hz. What will be the frequency of the output voltage.

62. When the base current in a transistor is changed from 30 μA to 80 μA, the collector current is changed from 1.0 mA to 3.5 mA. Find the current gain β.

63. The output of two NOT gates is made input for NOR gate. Name the new logic gate obtained and write down its truth table.



64. Using a suitable combination from a NOR, an OR and a NOT gate, draw circuits to obtain the truth table given below.

A	B	Y
0	0	0
0	1	0
1	0	1
1	1	0

(i)

A	B	Y
0	0	1
0	1	1
1	0	0
1	1	1

(ii)

SOLUTIONS

Brief Explanations of Selected Questions

EXERCISE

1. (a) For forward biasing of p-n junction, the positive terminal of external battery is to be connected to p-semiconductor and negative terminal of battery to the n-semiconductor.
2. (c) Semiconductors are insulators at room temperature.
3. (d) Due to heating, when a free electron is produced then simultaneously a hole is also produced.
4. (b) This truth table is of identity, $X = A + B$. Hence, OR gate.
5. (a) To use a transistor as an amplifier the emitter base junction is forward biased while the collector base junction is reverse biased.
6. (b) The amplifying action of a triode is based on the fact that a small change in grid voltage causes a large change in plate current. The AC input signal which is to be amplified is superimposed on the grid potential.
7. (a) The function of emitter is to supply the majority carriers. So, it is heavily doped
8. (b) When p-n junction is reverse biased, the flow of current is due to drifting of minority charge carriers across the junction.
9. (b) When A = 1, then $A + \overline{A} = 1 + 0 = 1$

   and when A = 0, then $A + \overline{A} = 0 + 1 = 1$
10. (c) This truth table is of the identity, $Y = \overline{A.B}$, hence, it is NAND gate.

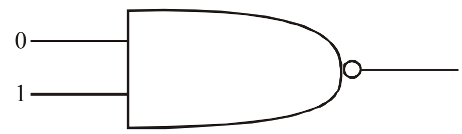
    Here, the output is high even if all inputs are low or one input is low.
11. (c) the given circuit is a circuit of full wave rectifier.
12. (a) Phosphorous (P) is pentavalent and silicon is tetravalent. Therefore, when silicon is doped with pentavalent impurity, it forms a n-type semiconductor.
13. (a) In an n-p-n transistor, the charge carriers, are free electrons in the transistor as well as in external circuit; these electrons flow from emitter to collector.
14. (a) Arsenic contains 5 electrons in its outermost shell. When Arsenic is mixed with silicon there is one electron extra in silicon crystal. Hence, such type of semi conductor is n-type semiconductor.
15. (c) p-type germanium semiconductor is formed when it is doped with a trivalent impurity atom.
16. (a) The given truth table is of

    (OR gate + NOT gate) $\equiv$ NOR gate
17. (d) (a) is a NAND gate so output is $\overline{1 \times 1} = \overline{1} = 0$

    (b) is a NOR gate so output is $\overline{0 + 1} = \overline{1} = 0$

    (c) is a NAND gate so output is $\overline{0 \times 1} = \overline{0} = 1$

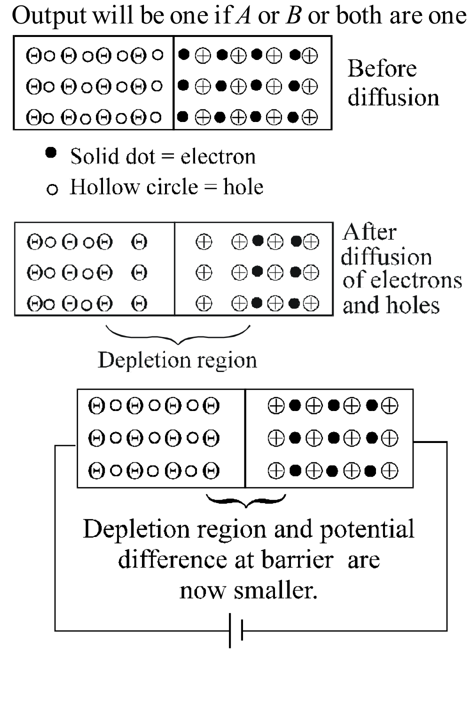
    (d) is a XOR gate so output is $0 \oplus 0 = 0$



Following is NAND Gate

$Y = \overline{A.B}$

18. (a) P, Q and R are related as $R = P.\,Q$ which is relation of AND gate.
19. (a) At 0K, motion of free electrons stop. Hence conductivity becomes zero. Therefore, at 0K intrinsic semiconductor becomes insulator.
20. (b) For conduction, p-n junction must be forward biased. For this p-side should be connected to higher potential and n-side to lower potential.
21. (c) When the collector is positive and emitter is negative w.r.t. base, it causes the forward biasing for each junction, which causes conduction of current.
22. (b) Barrier potential does not depends on diode design while barrier potential depends upon temperature, doping density, and forward biasing.
23. (c) In reverse biasing, the conduction across the p-n junction does not take place due to majority carriers but takes place due to minority carriers if the voltage of external battery is large. The size of the depletion region increases thereby increasing the potential barrier.
24. (c) In semiconductros, the conduction is empty and the valence band is completely filled at 0 K. No electron from valence band can cross over to conduction band at 0K. But at room temperature some electrons in the valence band jump over to the conduction band due to the small forbidden gap, *i.e.* 1 eV.
25. (c) Output will be one if A or B or both are one $Y = A + B$
26. (c)



Number of donors is more because electrons from -ve terminal of the cell pushes (enters) the n side and decreases the number of uncompensated pentavalent ion due to which potential barrier is reduced. The neutralised pentavalent atom are again in position to donate electrons.

27. (a) **28.** (d) **29.** (b) **30.** (b) **31.** (b)
32. (a) **33.** (a) **34.** (c) **35.** (b)
36. (b) In a p-type semiconductor, a hole is a missing elec tron in a covalent bond.
37. (c) **38.** (d) **39.** (d) **40.** (d) **41.** (d)
42. (b) **43.** (c) **44.** (a) **45.** (a) **46.** (b)
47. (c) **48** (d)
49. (a, c) **50.** (b, c) **51.** (a, c)
52. (a, b, d) At 0 K, the motion of electrons cease and so electric current becomes zero.
53. (b, d)The given logic current is

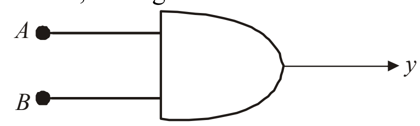
$OR + NOT \rightarrow NOR$

Also $\overline{X+Y} = \bar{X}.\bar{Y}$

54. (b) **55.** (a)
56. (b) These gates are called digital building blocks because using these gates only (either NAND or NOR) we can compile all other gates also (like OR, AND, NOT, XOR)
57. (c) Study of junction diode characteristics shows that the junction diode offers a low resistance path, when forward biased and high resistance path when reverse biased. This feature of the junction diode enables it to be used as a rectifier.
58. (b) A NOT gate puts the input condition in the opposite order, means for high input it give low output and for low input it give high output. For this reason NOT gate is known as invertor circuit.
59. (c) Assertion is true but reason is false.
The common base configuration of n-p-n transistor is used for voltage amplification. The current amplification is very small.
Assertion is true.
the collector is reverse biased for voltage amplification. The reason given has not mentioned that it is voltage amplification. The reason is therefore, incomplete by itself. It is wrong.
60. (c) (A)→p,r, s,; (B)→q, r; (C)→p,r; (D)→p,s
61. 50 Hz
62. We know that $\beta = \frac{\Delta i_c}{\Delta i_B} = \frac{(3.5-1.0)\times 10^{-3}}{(80-30)\times 10^{-6}} = 50$

63. $y = \overline{\overline{A}+\overline{B}} = \overline{\overline{A}}.\overline{\overline{B}} = A.B$

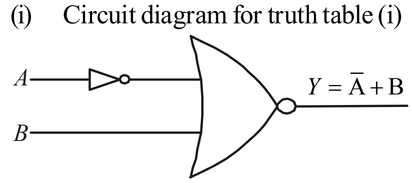
Hence, AND gate is formed.



Truth Table:

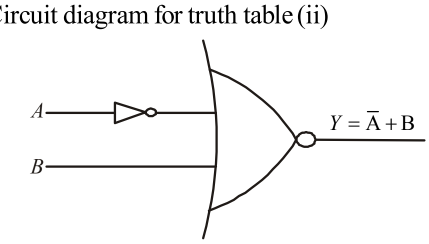
A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

64. (i) Circuit diagram for truth table (i)



A	B	$\bar{A}$	$\bar{A}+B$	$Y = \overline{\bar{A}+B}$
0	0	1	1	0
0	1	1	1	0
1	0	0	0	1
1	1	0	1	0

(ii) Circuit diagram for truth table (ii)



A	B	$\bar{A}$	$Y = \bar{A}+B$
0	0	1	1
0	1	1	1
1	0	0	0
1	1	0	1