Reflection

When a series of wave strike an obstacle, they are turned back. This turning back of waves is called reflection of waves. When waves strike a straight barrier, the waves are reflected from the barrier. The angle of incidence is equal to the angle of reflection as shown in Figure 7.12. The wavelength and velocity of the wave remain constant in reflection of wave.

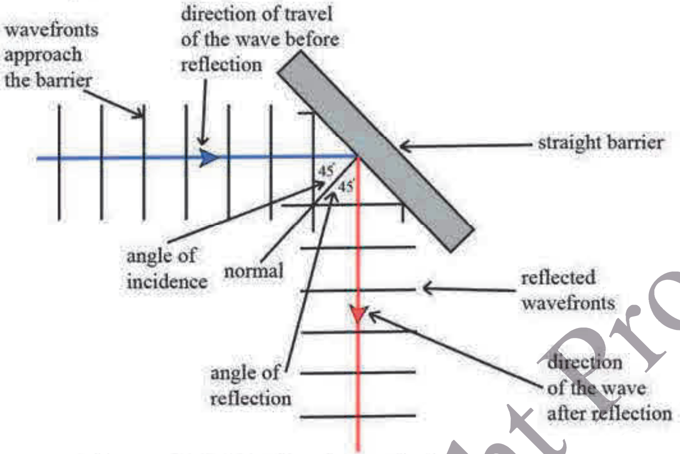


Figure 7.12 Reflection of plane wave

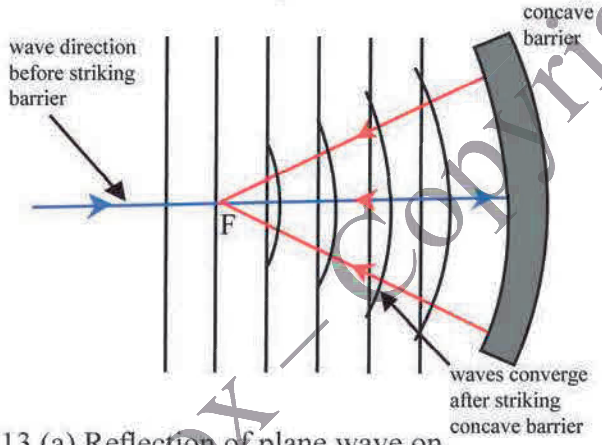


Figure 7.13 (a) Reflection of plane wave on concave surface

Figure 7.13 (b) Radio antenna
[https://en.m.wikipedia.org/wiki/yevpatoria-RT-70-radio-telescope]

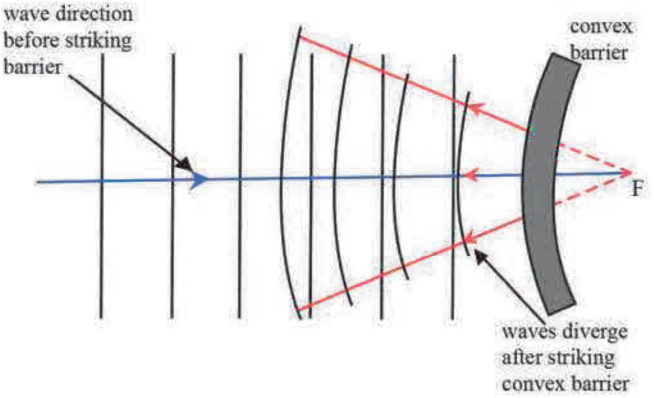


Figure 7.14 Reflection of plane wave on convex surface

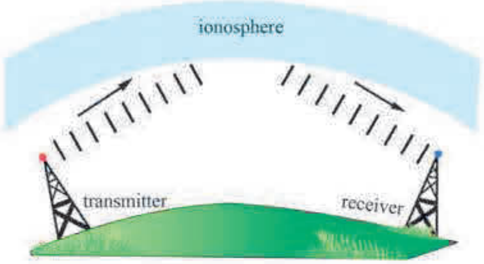


Figure 7.15 Reflection of radio waves

Refraction

The speed of water waves depends on the depth of water. It decreases when the depth of water becomes less deep. By the ripple tank experiment, when water waves pass from deep to shallow water the velocity of wave is lesser and the wavelength is shorter or vice-versa. When waves are incident to the boundary with an angle, the direction of the waves changes. Such a change in direction is called refraction. It can be noticed that in refraction, the wavelength and velocity change but frequency remains the same.

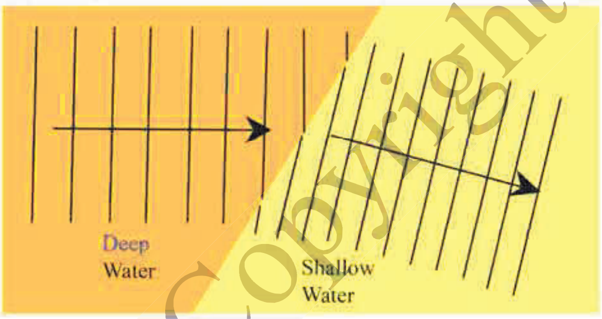


Figure 7.16 Refraction of plane wave

Diffraction

Diffraction is the spreading of waves from the straight-on direction through a gap (or) moves around an obstacle. The wave that passes the edges of the gap of the obstacle spread out. Figure 7.17 and 7.18 show water waves in ripple tank spreading out after they pass through the gap. In Figure 7.17 the wider the gap, the less the waves spread out. In Figure 7.18 the narrower the gap, the more the waves spread out. Note that the wavelength does not change after diffraction.

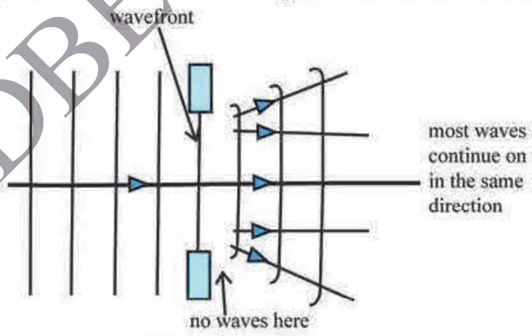


Figure 7.17 Diffraction of water waves through wide gap

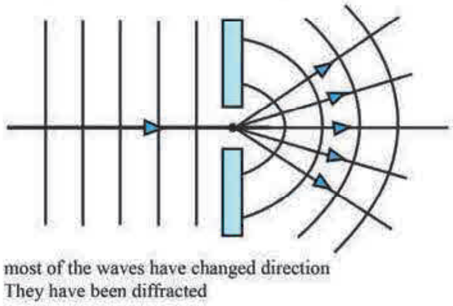


Figure 7.18 Diffraction of water waves through narrow gap

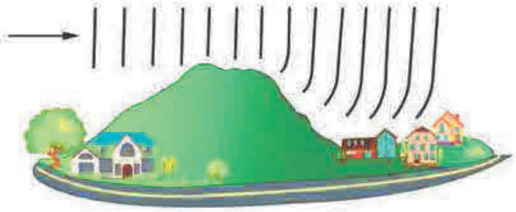


Figure 7.19 Diffraction of radio waves

Diffraction around an obstacle includes radio waves that are diffracted as they pass over the hill. (Figure 7.19)

Reviewed Exercise

1. What causes refraction of water waves?
2. Does the speed of water waves depend upon the depth of water?

Key Words: ripple tank, wavelength

7.6 SOUND WAVE AND SPEED OF SOUND

Sound Wave

Sound is a form of energy that is transferred from one place to another in a certain medium. Sound wave is produced by a vibrating object placed in a medium. The pressure changes occur alternately in the medium by vibrating object. The medium is usually air, but it can be any gas, liquid (or) solid. Sound wave propagates as a series of compression and rarefaction like longitudinal waves on a vibrating spring. Like other waves, sound wave can be reflected and diffracted.

Unlike electromagnetic waves, sound waves need a medium to propagate. Sound wave cannot travel through vacuum.

The compression is created in the medium as the vibrating object moves forward, since it pushes molecules together. The compression region has higher pressure. When the object moves back, the molecules are spread out and rarefaction is created and the pressure of that region is low. After the object is vibrated several times, it has created a series of compression and rarefactions travelling away from the vibrating object. The pressure of the medium is changed into higher and lower alternately. In this way, sound energy propagates through the medium to the ear. When waves enter the ear, they strike the ear drum and make it vibrate. This vibration of ear drum results the hearing of the sound. Sound energy is transferred through the medium by the successive pressure changes among the adjacent parts without moving the medium as a whole.

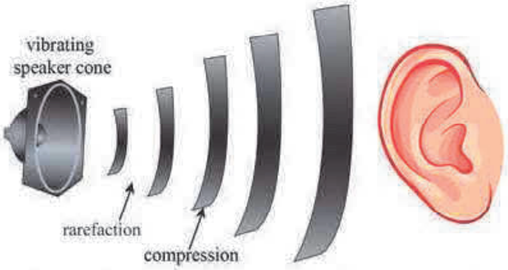


Figure 7.20 Vibrating loud speaker produces sound wave and travels through air to ear

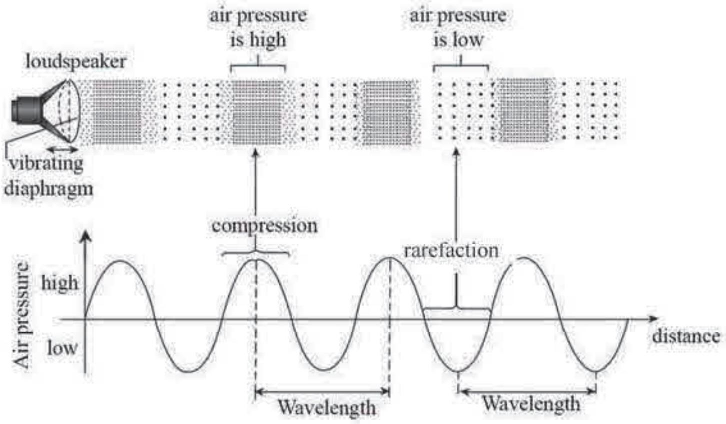


Figure 7.21 Pressure-distance graph of a propagated sound waves

Audible range : The average person can only hear sound that has a frequency higher than 20 Hz and lower than 20 000 Hz. This interval of frequency is called the audible range (or) hearing range. But the range becomes reduced according to age and health conditions. Sound waves with frequencies greater than 20 000 Hz are called ultrasounds. Some objects vibrating with frequencies under 20 Hz produces sound which cannot be heard by human. This is called infrasound.

It is found that, by experiments: dog, bat and dolphin can hear the ultrasound and they communicate with it. On the other hand, elephants can communicate with infrasound.

Speed of Sound

Since sound propagates from one place to another through a distance in a time interval in a given medium, the speed of sound is

$$\text{speed of sound} = \frac{\text{distance travelled by sound}}{\text{time taken}}$$

$$v = \frac{d}{t}$$

However, sound waves travels at different speeds in different media through which it passes. Generally, the speed of sound depends on the density of the medium. The denser the medium is, the greater the speed because the particles of the medium are tightly bound together. This means that the disturbance can be transferred more quickly from one particle to next.

Table 7.1 The speed of sound in some solids, liquids and gases

Medium	**Speed**		**Temperature °C**
	$m\ s^{-1}$	$ft\ s^{-1}$	
Air	332	1090	0
CO_2	259	850	0
Cl_2	206	676	0
Water, pure	1 404	4 605	0
Copper	3 560	11 680	20
Iron	5 130	16 830	20

Speed of sound in air varies with temperature. At 0°C the speed of sound in air is 332 m s^{-1}. Whenever the air temperature increases by 1°C, speed of sound will increase by 0.2 %. The speed of sound in air can be expressed as

$$v = 332\sqrt{\frac{T}{273}}$$

Here T is given in K and v in ms^{-1}. The above relation can be approximated by

$$v \cong 332 + 0.6\,(T - 273)$$

In air medium, the speed of sound increases by 0.6 m $s^{-1}$with temperature rise by one degree (1°C or 1 K).

Example (1) A distance of 0.33 m separates a wave crest from the adjacent trough, and the vertical distance from the top of a crest to the bottom of a trough is 0.24 m. What is the wavelength? What is the amplitude?

The wavelength, $\lambda = 2 \times 0.33 = 0.66$ m

The amplitude, $A = \dfrac{0.24}{2} = 0.12$ m

Example (2) What is the speed of a 256 Hz sound with a wavelength of 1.35 m?

The speed of sound $v = f\lambda = (256)\,(1.35) = 346$ m s^{-1}

Example (3) You dip your finger into a pan of water 14 times in 11s, producing wave crests separated by 0.16 m. (a) What is the frequency? (b) What is the period? (c) What is the velocity?

(a) The frequency, $f = \dfrac{14}{11} = 1.27$ Hz

(b) The period, $T = \dfrac{1}{f} = \dfrac{1}{1.27} = 0.79$ s

(c) The velocity, $v = f\lambda = (1.27)\,(0.16) = 0.20$ m s^{-1}

Example (4) A tall tree sway back and forth in the breeze with frequency of 2 Hz. What is the period of this?

The period, $T = \dfrac{1}{f} = \dfrac{1}{2} = 0.5$ s

Example (5) A typical sound wave associated with human speech has a frequency of 500 Hz and the frequency of the yellow light is about 5×10^{14} Hz. The velocity of sound in air is 344 m s^{-1} and the velocity of light is 3×10^{8} m s^{-1}. Find the wavelengths of the waves.

For the sound wave, $\lambda = \dfrac{v}{f} = \dfrac{344}{500} = 0.688$ m

For the light wave, $\lambda = \dfrac{c}{f} = \dfrac{3 \times 10^{8}}{5 \times 10^{14}} = 6 \times 10^{-7}$ m = 6 000 Å

Example (6) On a day when air temperature is 11ºC, you use a whistle to call your dog. If the wavelength of the sound produced is 0.015 m, what is the frequency? Could you hear the whistle?

The velocity of sound in air at 11 ºC is

$$v = 332\sqrt{\frac{T}{273}}$$

$$= 332\sqrt{\frac{273+11}{273}} = 332\sqrt{1.04} = 332 \times 1.02$$

$$= 338.62 \text{ m s}^{-1}$$

$$f = \frac{v}{\lambda} = \frac{338.62}{15 \times 10^{-3}}$$

$$= 22.57 \times 10^{3} \text{ Hz}$$

$$= 22\,570 \text{ Hz}$$

We could not hear the whistle (sound) because the human's ear is supposed to be able to hear sound with frequency that are greater than 20 Hz and less than 20 000 Hz.

Reviewed Exercise

1. How does the velocity of sound depend on the temperature of the medium through which its travels?
2. 'Generally, the denser the medium the greater will be the velocity of sound'. Explain this statement.

Key Words: compression, rarefaction, ultrasound, infrasound, frequency

SUMMARY

Transverse wave: If the displacements of particles of the medium are perpendicular to the direction of the wave, such a wave is called transverse wave.

Longitudinal wave: If the displacements of particles of medium are parallel to the direction of the waves, such a wave is called longitudinal wave.

Wavelength (λ): The distance between any two consecutive wave crests (or) two consecutive wave troughs is called wavelength.

Frequency (f): The number of complete waves passing a point per second is called frequency of waves.

Period (T): The time taken by the wave to travel the distance between any two consecutive wave crests (or) the time required for one complete vibration is called period of a wave.

Amplitude: The amplitude of a wave is the maximum value of displacement of vibrating element.

Velocity of wave (v): Velocity of wave is the speed with which a wave crest travels.

EXERCISES

1. Sound waves can travel in all the following except

A. solids C. air

B. liquids D. vacuum

2. How does the speed of sound vary in the following media; water, air and wood?

	Highest speed	Lowest speed
A.	Air	water
B.	Water	wood
C.	Wood	water
D.	Wood	air

3. Which one of the following statements is true for both sound and light waves?

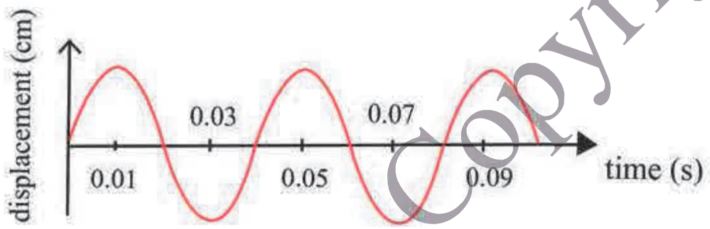
A. They are transverse waves.

B. They are reflected from a glass surface.

C. They travel faster in air than in water.

D. They are electromagnetic waves.

4.



The displacement of an air particle with time as a sound wave travels through the air is as shown above.

What is the frequency of the sound wave?

A. 10 Hz C. 50 Hz

B. 25 Hz D. 100 Hz

5. Which of the following is the normal audible frequency range of a human ear?

A. 0 - 10 000 Hz C. 20 - 20 000 Hz

B. 0 - 20 000 Hz D. 100 - 100 000 Hz

6. Which of the following frequencies of sound cannot be detected by the human ear?

A. 50 Hz C. 50 00 Hz

B. 500 Hz D. 50 000 Hz

7. A sound of frequency 400 Hz has a wavelength of 4.0 m in a medium. What is the speed of sound in the medium?

   A. $10^{-2}\ \mathrm{ms^{-1}}$ C. $1\,600\ \mathrm{ms^{-1}}$

   B. $100\ \mathrm{ms^{-1}}$ D. $8\,000\ \mathrm{ms^{-1}}$

8. A boy hears the thunder 2.0 s after seeing lighting flash. How far is the lighting flash from the boy? (Speed of sound $= 330\ \mathrm{ms^{-1}}$)

   A. 165 m C. 660 m

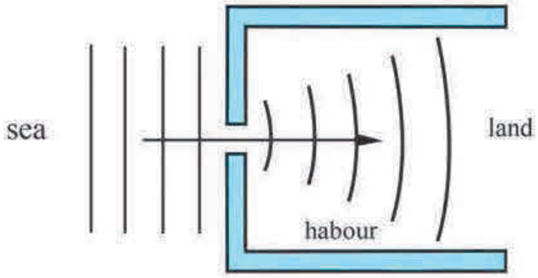
   B. 330 m D. 1320 m

9. Which of the following describes correctly the changes, if any, to the frequency, wavelength and speed of sound as is travels from air into water?

Frequency	Wavelength	Speed
A. Remains unchanged	decreases	decreases
B. Remains unchanged	increases	increases
C. Increases	increases	increases
D. Increases	remains unchanged	decreases

10. Define wavelength, frequency and velocity of a sound wave. Write down the relationship between them. Can this relationship be used for other waves (such as light waves)?
11. What are wavefronts?
12. What is meant by (a) reflection (b) refraction and (c) diffraction?
13. Are the following statements true (or) false? Correct the statements which are wrong.
    (a) The frequency of a wave is directly proportional to its wavelength.
    (b) Sound wave is transverse wave and water wave is longitudinal wave.
    (c) The velocity of sound is the same in water, air and helium gas.
    (d) Sound waves cannot travel through vacuum.
14. Find the wavelength of a wave with frequency 1 000 Hz and velocity $344\ \mathrm{m\ s^{-1}}$.
15. Find the frequency of a wave of velocity $200\ \mathrm{m\ s^{-1}}$ and wavelength 0.5 m.
16. A radar antenna emits electromagnetic radiation ($c = 3 \times 10^8\ \mathrm{m\ s^{-1}}$) of wavelength 0.03 m for 0.5 s. (a) Find the frequency of radiation. (b) How many complete waves are emitted in 0.5 s?
17. Find the frequency of a wave of 29 m wavelength telecast by a TV station. The velocity of that wave is the same as that of other electromagnetic waves and is $3 \times 10^8\ \mathrm{m\ s^{-1}}$.
18. The shortest wavelength of an ultrasonic wave emitted by a bat (in air at 0ºC) is 3.3 mm. What is the frequency of this wave? Is this frequency the largest (or) the smallest?
19. The frequency of a musical note in air is 440 Hz. What is the wavelength of that sound in sea water and in CO_2 gas? (Velocity of sound in sea water and CO_2 gas is $1\,440\ \mathrm{m\ s^{-1}}$ and $259\ \mathrm{m\ s^{-1}}$ respectively.)

20. What is the velocity of sound in air at 20 ºC?
21. If the temperature of the air medium is increased from 0 ºC to 40 ºC, by what percentage has the velocity of sound increased?
22. The diagram below shows water waves passing through the entrance of a model harbour.

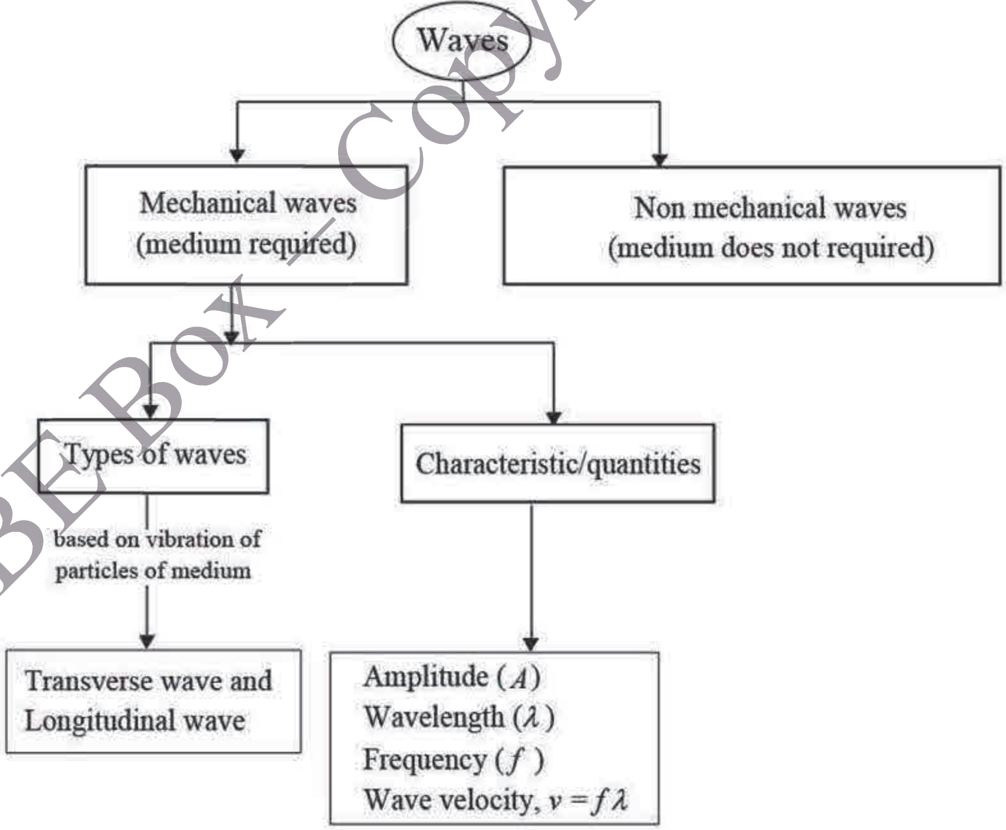


(a) Describe what happens to the waves as they leave gap between the harbour walls.

(b) What is this process called?

(c) Describe one change that could be made to the above arrangement in order to reduce this effect.

CONCEPT MAP



CHAPTER 8

LIGHT

When light travels through a uniform medium, whether it is vacuum, air (or) water, it always travels in a straight line. However, when the light encounters a different medium, some part of the light is absorbed, some is reflected and the rest is transmitted.

Learning Outcomes

It is expected that students will

- identify sources of light.
- examine the laws of reflection and the reflection of light at plane and curved surfaces.
- apply basic knowledge of optics to optical phenomena.
- draw ray diagrams for reflection of light on plane and curved surfaces.

The study of nature and propagation of light is known as optics. Optics is divided into two parts: geometrical optics and physical optics.

Geometrical optics is based upon the fact that light travels in a straight line. Ray diagrams are used in explaining the optical phenomena. On the other hand, physical optics is based upon the fact that light propagates by means of a wave-motion. Of these two, only geometrical optics will be studied in this chapter.

8.1 SOURCES OF LIGHT

Some objects such as the sun, the stars, fluorescent lamps and candles make their own light. These sources are called luminous sources. Most objects do not emit their own light but reflect light from luminous sources. They are non-luminous objects.

The sun is the chief source of light. The fact that light coming from the sun passes through the empty space on its way to the earth shows that light can travel through vacuum.

The speed of light has a definite value. All the forms of electromagnetic radiation, including light, travel at a speed of $3 \times 10^{8}\ \mathrm{m\ s^{-1}}$ in a vacuum. This speed is about one million times faster than that of sound.

Key Words: luminous, vacuum

8.2 REFLECTION OF LIGHT

When light is incident on the surface of an object some of the light is sent back and this phenomenon is called reflection of light. A ray of light is a path along which the light travels. A ray is represented by a straight line with an arrow-head. The arrow-head points in the direction of propagation of light.

A beam of light is a collection of rays of light. Figure 8.1, Figure 8.2 and Figure 8.3 show the parallel rays of light, the convergent rays and the divergent rays respectively.

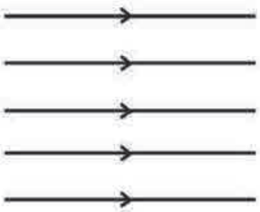


Figure 8.1 Parallel rays

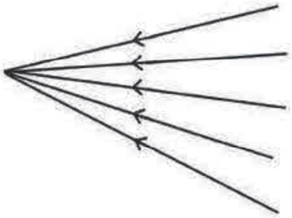


Figure 8.2 Convergent rays

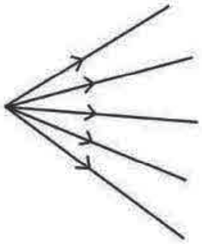


Figure 8.3 Divergent rays

Searchlights used in trains and lighthouses, emit parallel beam of light. Parallel beam of light become a convergent beam after passing through a convex lens. A beam emitted by a light bulb is a divergent beam.

In Figure 8.4, a ray which represents the incident light is an incident ray (AO). A line perpendicular to the surface at the point of incidence is called normal (NO). A ray which represents the reflected light is a reflected ray (OB). An angle between the incident ray and the normal is an angle of incidence (i) and an angle between the reflected ray and the normal is an angle of reflection (r).

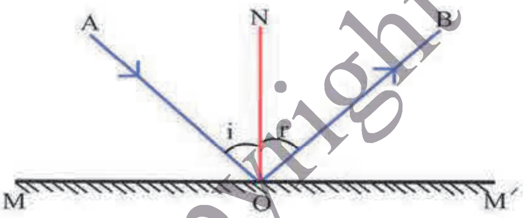


Figure 8.4 Illustration of reflection of light at a plane surface

Laws of Reflection

(1) The incident ray, the reflected ray and the normal all lie in the same plane.

(2) The angle of incidence is equal to the angle of reflection.

Laws of reflection are true for all reflecting surfaces for plane mirrors as well as curved mirrors.

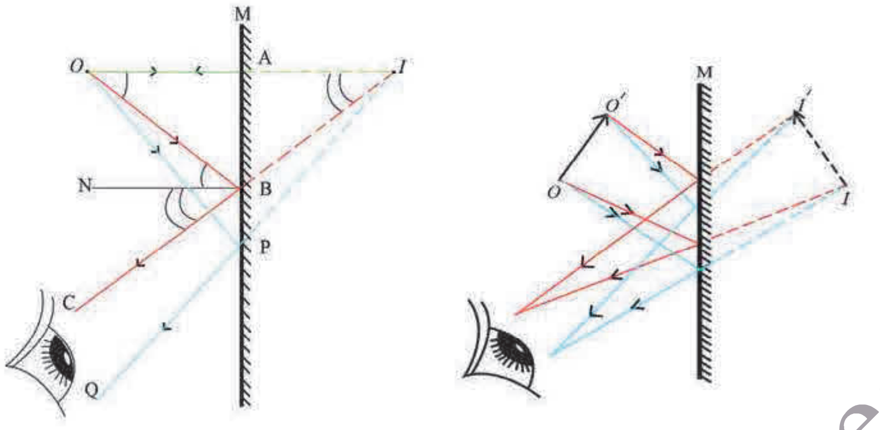
Reviewed Exercise

1. Give the names of light source which emit parallel beam and divergent beam.
2. Check the laws of reflection using a plane mirror.

Key Words: divergent beam, convergent beam, parallel beam

8.3 IMAGE FORMATION IN A PLANE MIRROR

An object having a smooth reflecting surface is called a mirror. A common mirror is a plane mirror. If the reflecting surface is plane, the mirror is called a plane mirror. A looking glass is one kind of a plane mirror. Figure 8.5 (a) and Figure 8.5 (b) are shown the formation of image of a point object and an extended object due to a plane mirror.



(a) (b)

Figure 8.5 Formation of images of a point and an extended object

In Figure 8.5 (a), the image I is observed as the reflected rays enter the eye. The reflected rays appear to diverge from I. The reflected rays do not actually pass through the image; only the reflected rays produced backwards pass through it. Such an image is called virtual image. The virtual image cannot be formed on a screen. The image formed by the actual intersection of the reflected rays is a real image. A real image can therefore be focused on a screen.

In Figure 8.5 (b), II' is the image of an object OO'. The object OO' can be considered as an object formed by several point objects. I is the image of a point O and I' is that of a point O'. The points between O and O' have the corresponding images between I and I'.

Lateral Inversion

Suppose that a man is looking himself (at his image) in a looking glass. When he tilts his head to the right, the head of the image in the mirror is found to tilt to the left, and vice versa. This effect is called lateral inversion. Examples of this phenomenon are also demonstrated in Figures 8.6 and 8.7.

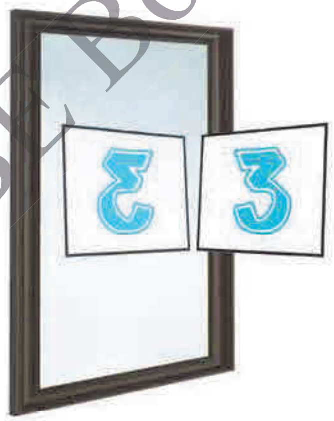


Figure 8.6 Lateral inversion of a number

Figure 8.7 Lateral inversion of a word

Properties of an Image in a Plane Mirror

The properties of an image formed in a plane mirror are as follows:

1. The image is of the same size as the object.
2. The image is virtual.
3. The image is erect.
4. The image is laterally inverted.
5. The image is situated on the line passing through the object and perpendicular to the plane mirror.
6. The image is as far behind the mirror as the object is in front.

Principle of Reversibility of Light

In Figure 8.8, if the direction of a ray of light is reversed, the light ray will travel along its original path. This is known as the principle of reversibility of light. This principle is valid also for refraction of light.

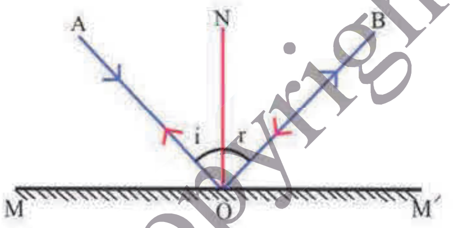
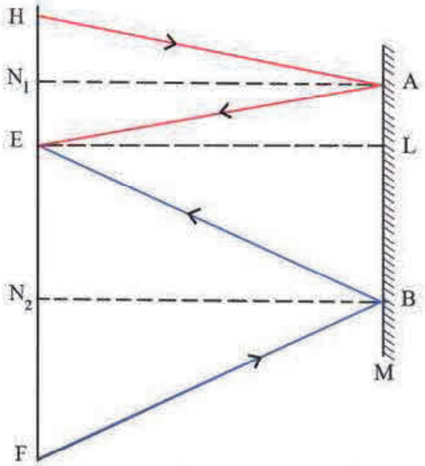


Figure 8.8 Illustration of reversibility of light

Example (1) A man 5 ft 6 in tall and whose eye level is 5 ft 2 in above the ground, looks at his image in a looking glass. What is the minimum vertical length of the looking glass if the man is to be able to see the whole of himself?



In the above Figure M is the looking glass. H represents the man's head, E his eyes and F his feet, respectively.

Therefore, $HF = 66$ in, $EF = 62$ in and $HE = 66 - 62 = 4$ in

For the man to be able to see his head, an incident ray from H to the top A of M must reflected to his eyes E.

Since the normal AN_1 bisects HE

$$AL = EN_1 = \tfrac{1}{2} HE$$
$$= \tfrac{1}{2} \times 4 = 2 \text{ in}$$

For the man to be able to see his feet F, a ray from F incident at the bottom B of mirror M must be reflected to his eyes E.

Since the normal BN_2 bisects EF,

$$LB = EN_2 = \tfrac{1}{2} EF$$
$$= \tfrac{1}{2} \times 62 = 31 \text{ in}$$

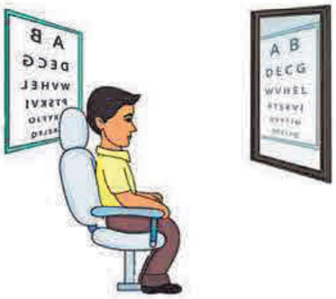
Therefore, the minimum vertical length of $M = AL + LB$

$$= 2 + 31 = 33 \text{ in} = 2 \text{ ft } 9 \text{ in}$$

The looking glass must have a minimum vertical length of 2 ft 9 in, which is half of the height of the man.

Some Applications of Plane Mirrors

(i) Optical Testing



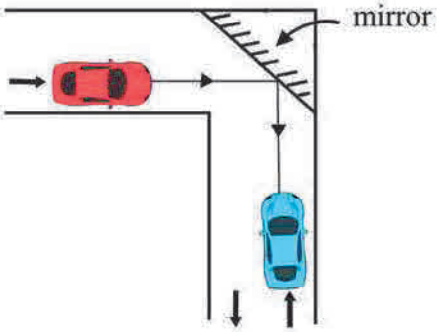
If the eye testing room is not large enough, the illuminated laterally inverted letters are placed behind the patient. These letters are seen correctly in the plane mirror which is in front of the patient.

(ii) Periscope

When the view of an object is obstructed by an obstacle, the periscope can be used to see the object clearly. The periscopes in submarines use prisms instead of mirrors. In addition, periscopes are attached with telescopes to observe very distant objects.

(iii) Blind Corners

Fitting a plane mirror at a corner allows drivers to see around blind turns (The diagram is not drawn to scale).



(iv) Instrument Scales

By forming an image of the pointer, the plane mirror eliminates parallax errors in the reading of instrument scales.

Plane mirrors are also used in many optical instruments such as telescopes, overhead projectors as well as lasers. Another common use of the plane mirror is in the construction of a kaleidoscope which gives colourful multiple images of pieces of coloured glass (or) plastic.

Reviewed Exercise

1. What are differences between real and virtual images?
2. What does it mean to say that a plane mirror produce a virtual image?

Key Words : mirror, lateral inversion, real image, virtual image

8.4 REFLECTION AT CURVED MIRROR

If only a small part of the surface of a curved mirror is used for reflection, it can be considered as an outer (or) an inner surface of a hollow sphere. Only concave and convex mirrors having spherical surfaces are used in most applications. We shall now discuss the reflections at such mirrors.

(a) Concave Mirror

If the reflecting surface of a mirror forms part of the inner surface of a hollow sphere, the mirror is called a concave mirror.

(b) Convex Mirror

If the reflecting surface of a mirror forms part of the outer surface of a hollow sphere, the mirror is called a convex mirror.

(c) Pole of a Concave (or) Convex Mirror

The centre of the surface of a concave (or) convex mirror is called its pole.

(d) Centre of Curvature of a Concave (or) Convex Mirror

The centre of a sphere, part of whose surface is the concave (or) convex mirror, is called the centre of curvature of that mirror.

(The centre of curvature of a concave mirror is in front of the reflecting surface and that of a convex mirror is behind the reflecting surface.)

(e) Radius of Curvature of a Concave (or) Convex Mirror

The radius of a sphere, part of whose surface is the concave (or) convex mirror, is called the radius of curvature of that mirror.

(f) Principal Axis

The line passing through the centre of curvature and the pole of a concave (or) convex mirror is called the principal axis.

(g) Principal Focus of a Concave Mirror

When the rays parallel and close to the principal axis are incident on a concave mirror the reflected rays pass through a point on the principal axis. That point is called the principal focus of the concave mirror. Since the reflected rays actually intersect at that point, the focus of a concave mirror is a real focus.

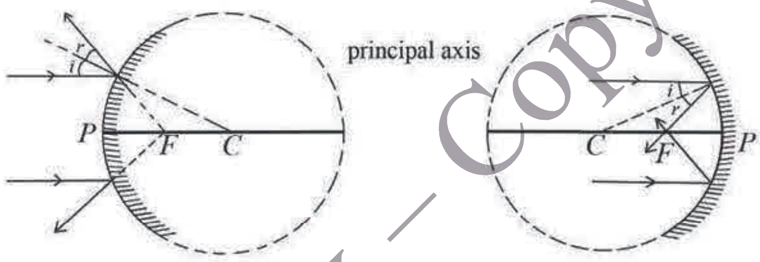
(h) Principal Focus of a Convex Mirror

When the rays parallel and close to the principal axis are incident on a convex mirror the reflected rays appear to come from a point on the principal axis. That point is called the principal focus of the convex mirror .Since the reflected rays do not actually pass through that point, the principal focus of a convex mirror is a virtual focus.

(i) Focal Length

The distance between the pole and the focus of a concave (or) convex mirror is called the focal length of the concave (or) convex mirror.

Figure 8.9 illustrates the stated definitions and the corresponding symbols.



P = pole

C = centre of curvature

F = focus

$PF = f$ = focal length

$PC = R$ = radius of curvature

Figure 8.9 Reflection at convex and concave mirrors

Relation Between Focal Length and Radius of Curvature

For rays close to the principal axis and for rays which make very small angles with the principal axis, we can show that focal length f is approximately equal to the half of the radius of curvature R, that is $f = \frac{R}{2}$.

Formation of Images in a Concave Mirror

The formation of images in the concave mirror for various positions of the object are shown in Figures 8.10 - 8.15.

In Figure 8.10 the object is at infinity and its image is

1. at F,
2. real,
3. inverted and
4. smaller than the object.

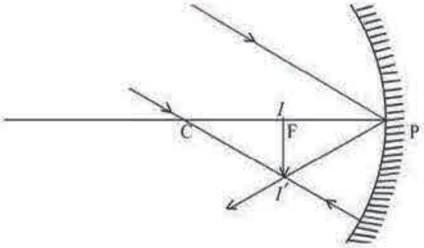


Figure 8.10 The object at infinity

In Figure 8.11 the object is beyond C and its image is

1. between C and F,
2. real,
3. inverted, and
4. smaller than the object.

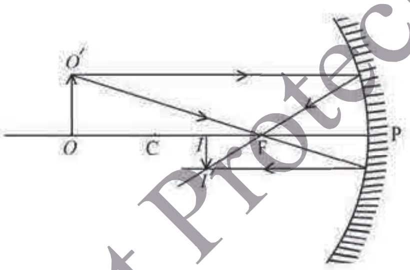


Figure 8.11 The object beyond C

In Figure 8.12 the object is at C and its image is

1. at C,
2. real,
3. inverted, and
4. of the same size as the object.

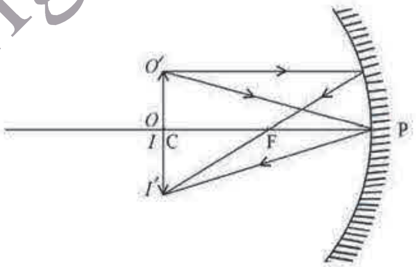


Figure 8.12 The object at C

In Figure 8.13 the object is between C and F and its image is

1. beyond C,
2. real,
3. inverted, and
4. larger than the object.

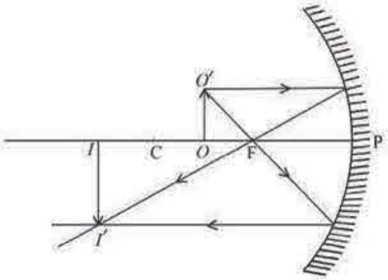


Figure 8.13 The object between C and F

In Figure 8.14 the object is at F and its image is at infinity

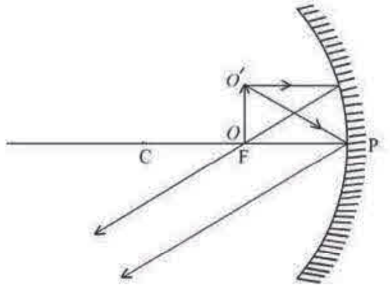


Figure 8.14 The object at F

In Figure 8.15 the object is between F and P and its image is

1. behind the mirror,
2. virtual,
3. erect, and
4. larger than the object.

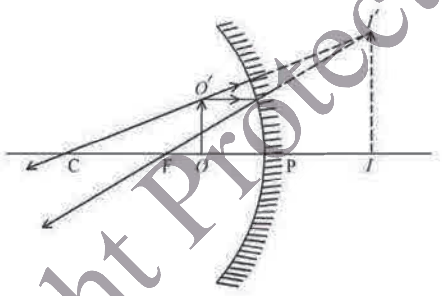


Figure 8.15 The object between F and P

Formation of Images in a Convex Mirror

The image formed in the convex mirror is always virtual, erect and smaller than the object. It is formed between P and F no matter where the object is situated (Figure 8.16).

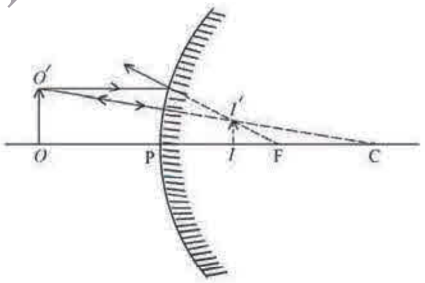


Figure 8.16 Image formed by a convex mirror

The image formed in the concave mirror can be real (or) virtual depending upon the position of the object. In addition, it may be erect (or) inverted. However the images of an object formed in plane and convex mirror are always virtual.

Some Applications of Curved Mirrors

Convex mirrors are often used as rear view mirrors of vehicles since they always give an erect image and a wide field of view. Figure 8.17 illustrates a convex mirror has a wider field of view than a plane mirror of the same size.

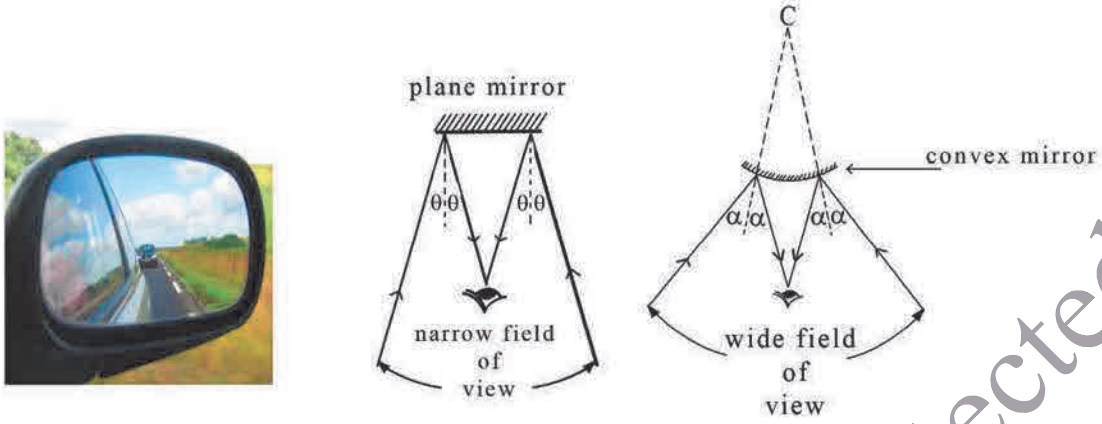


Figure 8.17 Practical use of a convex mirror and advantage of convex mirror as a rear view mirror

Concave mirrors are normally used as reflectors in motor car headlamps, torchlights and searchlights. A concave mirror may also be used as a shaving mirror since it is able to produce an enlarged image of the object shown in Figure 8.18.

Figure 8.18 Practical use of concave mirror

Sign Conventions

We have observed that the focus of a concave mirror is real and that of a convex mirror is virtual. Moreover, the images formed in these mirrors may either be real (or) virtual, and erect (or) inverted. Hence the following sign conventions are required in applying mirror formulae to solve the problems.

1. Distances of real object, real image and real focus are positive. Distances of virtual object, virtual image and virtual focus are negative.
2. The focal length and radius of curvature of a concave mirror are positive, and those of a convex mirror are negative.
3. The perpendicular distance measured above the principal axis is positive and that below the principal axis is negative.

Mirror Formula

For both concave and convex mirrors

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f} \qquad (8.1)$$

where u = object distance from the mirror
v = image distance from the mirror
f = focal length

All distances are measured from the pole of the mirror.

Magnification

The images formed by the concave and convex mirrors have various sizes depending upon the position of the object. Thus, the lateral magnification produced by a mirror is defined as the ratio of the height of the image to the height of the object.

$$\text{Magnification} = \frac{\text{height of image}}{\text{height of object}} = \frac{\text{size of image}}{\text{size of object}}$$

If m = magnification, II' = size of image and OO' = size of object

then $$m=\frac{II'}{OO'} \qquad (8.2)$$

The magnification m can also be expressed in terms of the object distance u, and the image distance v.

$$\frac{II'}{OO'}=-\frac{v}{u} \qquad (8.3)$$

The minus sign determines both the nature and configuration of the image.

The formula for the magnification m can be expressed as $m=\frac{II'}{OO'}=-\frac{v}{u}$

Example (2) An object is placed (a) 20 cm (b) 4 cm in front of a concave mirror of focal length 12 cm. Find the nature and position of the image in each case.

(a) $u = +20$ cm

$f = +12$ cm(concave mirror)

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

$$\frac{1}{+20}+\frac{1}{v}=\frac{1}{+12}$$

$$\frac{1}{v}=\frac{1}{12}-\frac{1}{20}$$

$$v = 30 \text{ cm}$$

Since v is positive the image is real. It is formed 30 cm from the concave mirror on the same side as the object.

(b)

$$u = +4 \text{ cm}$$

$$\frac{1}{u}+\frac{1}{v} = \frac{1}{f}$$

$$\frac{1}{+4}+\frac{1}{v} = \frac{1}{+12}$$

$$\frac{1}{v} = \frac{1}{12}-\frac{1}{4}$$

$$v = -6 \text{ cm}$$

Since v is negative, the image is virtual. It is formed 6 cm behind the concave mirror.

Example (3) An object is placed 10 cm in front of a concave mirror of focal length 15 cm. Find the image position and the magnification.

$$u = +\,10 \text{ cm}$$

$$f = +15 \text{ cm (concave mirror)}$$

$$\frac{1}{u}+\frac{1}{v} = \frac{1}{f}$$

$$\frac{1}{+10}+\frac{1}{v} = \frac{1}{+15}$$

$$\frac{1}{v} = \frac{1}{15}-\frac{1}{10}$$

$$v = -30 \text{ cm}$$

Since v is negative, the image is virtual. It is formed 30 cm behind the concave mirror.

$$\text{Magnification} \quad m = -\frac{v}{u}$$

$$m = -\frac{(-30)}{10} = 3$$

Since $m = \dfrac{II'}{OO'} = 3$ or $II' = 3 \times OO'$, it can be said that the image is 3 times the size of the object and it is erect.

Example (4) The image of an object in a convex mirror is 4 cm from the mirror. If the mirror has a radius of curvature of 24 cm. Find the object position and the magnification.

The image in a convex mirror is always virtual.

$$v = -\,4 \text{ cm (virtual image)}$$

$$R = -\,24 \text{ cm (convex mirror)}$$

$$R = 2f\,,\; f = \frac{R}{2} = (\frac{-24}{2}) = -12 \text{ cm}$$

$$\frac{1}{u}+\frac{1}{v} = \frac{1}{f}$$

$$\frac{1}{u}+\frac{1}{-4} = \frac{1}{-12}$$

$$\frac{1}{u} = \frac{1}{-12} + \frac{1}{4}$$

$$u = 6 \text{ cm}$$

Since u is positive, the object is real. It is 6 cm from the convex mirror.

$$\text{Magnification } m = -\frac{v}{u}$$

$$m = -\frac{(-4)}{6}$$

$$m = \frac{2}{3}$$

Since $m = \frac{II'}{OO'} = \frac{2}{3}$ (or) $II' = \frac{2}{3} \times OO'$, the size of the image is $\frac{2}{3}$ times the size of the object and the image is erect.

Example (5) The image of an object in a concave mirror is erect and three times the size of the object. If the mirror has a radius of curvature of 36 cm, find the position of the object.

Size of the image = 3 × size of object

$$II' = +3 \times OO' \quad \text{(erect image)}$$

$$\frac{II'}{OO'} = +3$$

$$m = +3$$

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

$$+3 = -\frac{v}{u}$$

$$v = -3u$$

$$R = +36 \text{ cm} \quad \text{(concave mirror)}$$

$$f = \frac{R}{2} = \frac{36}{2} = 18 \text{ cm}$$

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

$$\frac{1}{u} + \frac{1}{-3u} = \frac{1}{18}$$

$$\frac{2}{3u} = \frac{1}{18}$$

$$u = 12 \text{ cm}$$

The object is placed 12 cm from the concave mirror.

SUMMARY

When light is incident on the surface of an object some of the light is sent back and this phenomenon is called **reflection of light.**

The Laws of Reflection states that

(1) The incident ray, the reflected ray and the normal all lie in the same plane.

(2) The angle of incidence is equal to the angle of reflection.

If the reflecting surface is plane, the mirror is called a **plane mirror.**

If the direction of a ray of light is reversed, the light ray will travel along its original path. This is known as **the principle of reversibility of light.**

EXERCISES

1. State the laws of reflection of light.
2. Give two examples each of objects which (a) emit their own light (b) are only visible because they reflect light from another source.
3. A man is looking into a plane mirror on the wall which is 6 ft away from him. He views the image of a chart which faces the mirror and is 2 ft behind him. Find the distance between his eyes and the image of the chart.
4. Draw a ray diagram to show that a vertical plane mirror need not be 5 ft long in order that a boy 5 ft tall may see a full-length image of himself in it.
5. In the above problem, if the boy's eyes are 4 in below the top of his head, find the height of the base of the mirror above floor level.
6. Show that a point object and its image are at equal distance from any point on the plane mirror.
7. What is meant by lateral inversion? The letter R is 5 cm in front of a plane mirror. Draw accurately the image of R in the mirror.
8. State the similarities and differences between the virtual images formed by the concave and convex mirrors.
9. When a ray parallel to the principal axis is incident on a concave mirror, it passes through the focus after reflection. By using the laws of reflection, prove that $f = \frac{R}{2}$.
10. Choose the correct answer from the following:
    A. Only a virtual image smaller than the object is formed by a concave mirror.
    B. Only a virtual image larger than the object is formed by a convex mirror.
    C. The statement given in A and B are wrong.
11. Choose the correct answer from the following:
    A. Only real images are formed by a concave mirror.
    B. Real and virtual images can be formed by a concave mirror.
    C. Real and virtual images can be formed by a convex mirror.

12. Choose the correct answer from the following:
    When an object is at the centre of curvature of a concave mirror the magnification is
    A. 0.5 B. −1.0 C. 1.5

13. A concave mirror can produce an image which is twice the size of the object. Draw a ray diagram to show this.

14. An image is 6 cm from a convex mirror which has a radius of curvature of 36 cm. Find the object position and the magnification.

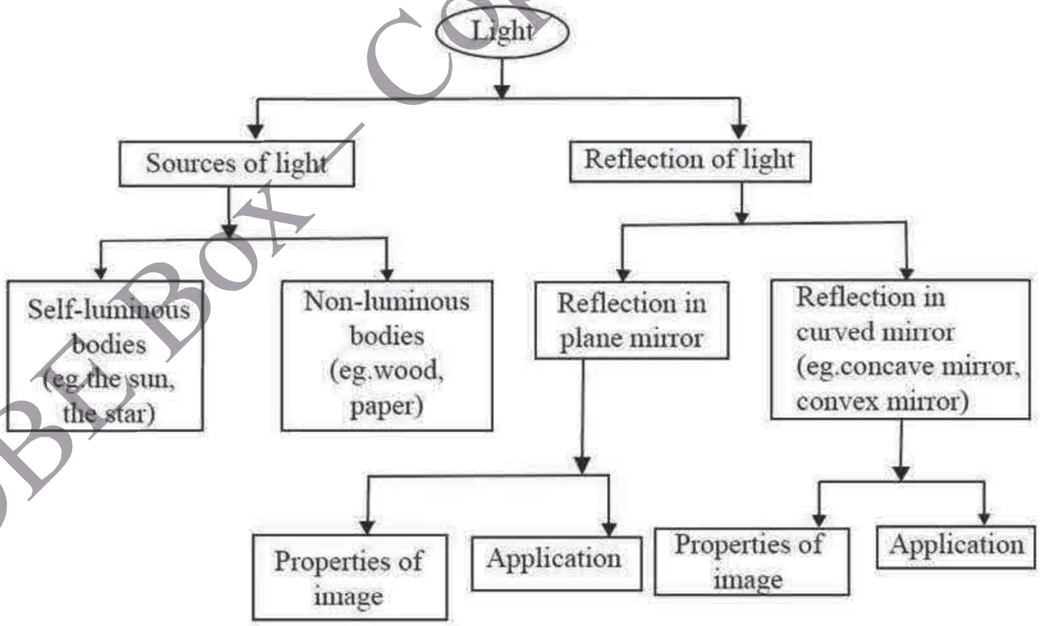
15. An image one-third the size of an object is formed by a convex mirror of focal length 15 cm. How far is the object from the convex mirror?

16. An object is 20 cm in front of a concave mirror of focal length 15 cm. How far must the screen be placed from the centre of curvature of the concave mirror to receive the image of the object? If the object is 2 cm tall, find the size of the image.

17. An object is 20 cm from a mirror. If the virtual image is half the size of the object, find the radius of curvature of the mirror.

18. An object is placed 30 cm in front of a concave mirror of focal length of 10 cm. Find the image position and the magnification.

CONCEPT MAP



CHAPTER 9

ELECTRICITY

Electricity is a form of energy. There are two types of electricity: electrostatics (or) static electricity and electrodynamics (or) current electricity. Electrostatics is the study of electric charge at rest. Electrodynamics is the study of moving electric charges and their interaction with magnetic and electric fields. In this chapter, charges at rest (electrostatic charges) and electrification are studied.

Learning Outcomes

It is expected that students will

- investigate electric charges.
- distinguish the repulsive and attractive force between two charges.
- discuss that a charged body has electron deficiency (or) excess.
- identify the characteristics of conductors, insulators and semiconductors.
- explain the process of charging by induction.
- demonstrate an understanding of electrification and nature of electrostatic force.
- apply basic knowledge of electrostatics to daily-life uses.

Electric charge (or) electricity, can be provided by batteries and generators. But some materials become charged when they are rubbed. These charges are electrostatic charge or static electricity.

The two kinds of static electric charge are positive charge and negative charge. The uses of static electricity are electrostatic precipitators, inkjet printers and photocopiers. Another example of static electricity is lightning discharge.

Electrical energy can be transformed into other forms of energy, such as heat energy, mechanical energy, light energy and sound energy. It is used in domestic electric appliances, in industries, transportation and communication works. In technologically advanced countries scientists are trying to generate considerable amount of electrical energy from the wind, from the sea and from the sun.

9.1 ELECTRIC CHARGES AND ELECTRIC FORCES

Electric charge is the physical property of matter that causes an electric force when placed in an electromagnetic field. Electric charges may be either at rest (static charges) (or) in motion (moving charges). Flow of charges is called an electric current.

[https://en.m.wikipedia.org/wiki/Benjamin_Franklin] **Benjamin Franklin**
(1706-1790)

A French scientist, Du Fay, studied the nature of electric charges possessed by substances and found that there were only two kinds of charges. Benjamin Franklin named them positive charge which is represented by a plus sign (+) and negative charge by a minus sign (−). Like charges repel and unlike charges attract. The closer the charges are, the greater the force between them. When two charged objects are brought together, they produce either attractive (or) repulsive force (Figure 9.1).

The electric force between two charged objects is one of the fundamental forces of nature. The electric force holds the particles that make up an atom together. Charged objects can exert forces to other charged objects without being in contact with them. This is possible because there is an electric field around each charge.

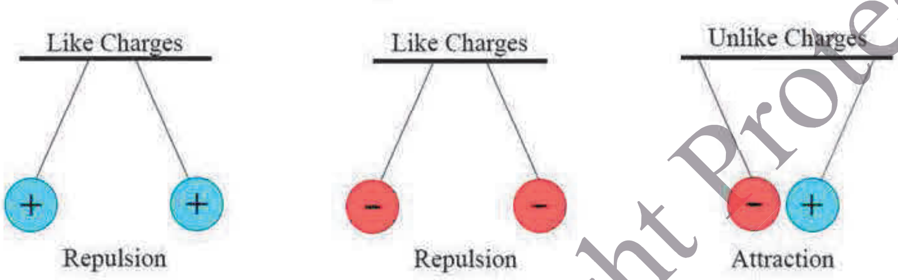


Figure 9.1 Repulsion and attraction between like and unlike charges

Unit of charge

In SI units, electric charge is measured in coulomb (C), in honour of Charles Augustin de Coulomb, a French physicist. He discovered that the force between two charged objects depends on the magnitude of their charges and on how far apart they are. Since the magnitude of charge of an electron is 1.6×10^{-19} C, one coulomb of charge is equivalent to the charge of 6.25×10^{18} electrons. One coulomb is a relatively large value of charge.

Charles de Coulomb, Physicist, Scientist (1736–1806)

[https://www.biography.com/scientist/charles.de-coulomb]

1 microcoulomb (1 μC) = 10^{-6} C (one millionth of a coulomb)

Charge is one of the quantized physical quantities. It means that charge cannot take any arbitrary values, but only discrete values that are integral multiples of the fundamental charge that is charge of an electron.

$Q = n\,e$, where Q = electric charge, n = integer, e = charge of an electron = 1.6×10^{-19} C

Reviewed Exercise

- When two bodies attract each other electrically, must both of them be charged?

Key Words: positive charge, negative charge, repulsive force, attractive force, quantized

9.2 MATTER AND ELECTRICITY

Matter is composed of atoms which are very small in size. An atom consists of core called the nucleus around which the particles called electrons are moving in orbits.

An electron is a negatively charged particle having a charge of -1.6×10^{-19} C. The nucleus consists of two kinds of particles called proton and neutron. A proton is a positively charged particle and a neutron is an uncharged particle. An electron and a proton have the same magnitude of electric charge. The nucleus has net positive charge. The magnitude of positive charge of the nucleus is equal to the sum of the positive charges of all the protons present in the nucleus.

In a normal atom the number of orbiting electrons is always equal to the number of protons. Since the magnitude of positive charge of the nucleus is equal to that of the total negative charge of electrons, a normal atom has no net charge. It is said to be electrically neutral.

If an atom gains one (or) more electrons, it carries a negative charge. If an atom loses one (or) more electrons, it becomes positively charged. When an atom becomes a charged atom, it is called an ion.

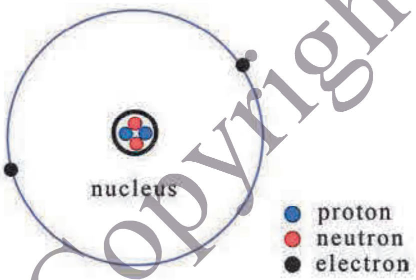


Figure 9.2 A neutral atom (helium) has the same number of electrons and protons

Reviewed Exercise

- Why does a nucleus possess the positive charge?

Key Words: atom, proton, electron, neutron

9.3 CONDUCTORS, INSULATORS AND SEMICONDUCTORS

As already mentioned, in an atom the negatively charged electrons are moving around a positively charged nucleus. Some of these electrons are near the nucleus while other electrons are further away from the nucleus. Since positive and negative charges attract each other, electrons experience an attractive force of the nucleus. As the attractive force is greater for the electrons closer to the nucleus so these electrons cannot move freely. This means that the inner electrons are tightly bound by the nucleus. The electrons closer to the nucleus are called bound electrons.

The electrons far away from the nucleus (or) the outer electrons experience less attractive force of the nucleus. This means that the outer electrons are loosely bound and are called free electrons. They can move from one atom to another.

The number of free electrons in a substance depends upon the nature of that substance. The substance which has plenty of free electrons is called a conductor and the substance which has very few (or) no free electrons is called an insulator.

Metals are good electrical conductors. Some of their electrons are so loosely held to their atoms that they can pass freely from atom to atom. These free electrons make metals good conductors. Most non-metals conduct electricity poorly (or) not at all, although carbon is an exception.

In insulators all the electrons are held tightly in position and unable to move from atom to atom. Insulators are materials that hardly conduct electricity. Although the electrons are not free to move in insulators, they can be transferred from one object to another.

Some substances which contain a moderate amount of free electrons are called semiconductors. Such substances are neither conductors nor insulators. Silicon and germanium are widely used as semiconductors.

Metals such as gold, silver, copper, brass, aluminium etc., are good conductors.
Non-metals such as plastic, glass, rubber, wax, quartz, etc., are insulators.
Transistors and other electronic components are made from semiconductors.

Reviewed Exercise

1. What do you understand by a bound electron and a free electron?
2. Is your body a conductor (or) an insulator? Mention five insulators and five conductors.
3. There are very large numbers of charged particles in most objects. Why then, don't most objects exhibit static electricity?

Key Words: bound electrons, free electrons, conductor, insulator, semiconductor

9.4 ELECTRIFICATION

(1) Electrification by Rubbing

Normally, atoms have equal numbers of electrons and protons so the net (overall) charge on a material is zero. However, when the two insulating materials are rubbed together, electrons may be transferred from one to the other. If two uncharged objects are rubbed with one another both of them become charged. This is also called charging by friction.

It is important that the rubbing does not produce (or) create charge. It simply removes the electrons from one object and transfers them to the other. As shown in Figure 9.3 when a glass rod is rubbed with a silk cloth, the glass rod becomes positively charged while the silk cloth is negatively charged. This is because some electrons of the glass rod are transferred to the silk cloth. Hence, the glass rod loses electrons while the silk cloth gains electrons.

As another example, when a plastic rod is rubbed with fur, the plastic rod possesses a negative charge while the fur becomes positively charged.

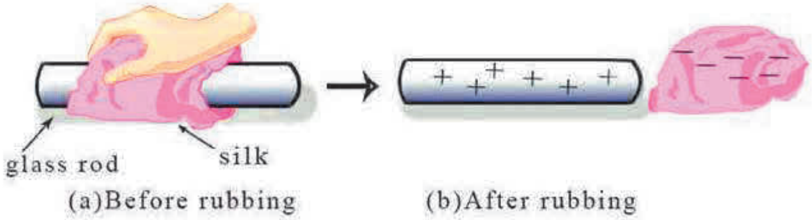
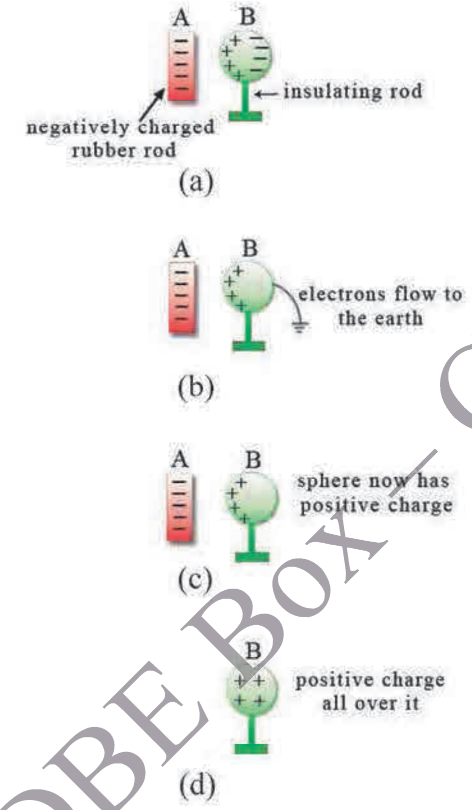


Figure 9.3 A glass rod is rubbed with a silk cloth

(2) Electrification by Induction

(i) Charging a single metal conductor by induction

Induction is the process of charging a conductor without any contact with the charged body. A charged object can attract uncharged objects. We start with two objects: an object A (negatively charged rod) and an uncharged metal sphere B on an insulating stand. The method is as follows.



Step 1

Object A is a negatively charged rod. When the metal sphere B is placed near it, like charges repel so electrons in the sphere move to right side of the sphere.

Step 2

Now the sphere is touched, by hand (or) by a wire connected to earth. Electrons flow from the sphere to the earth through the wire.

Step 3

The connection is removed. Now the sphere becomes a positively charged object.

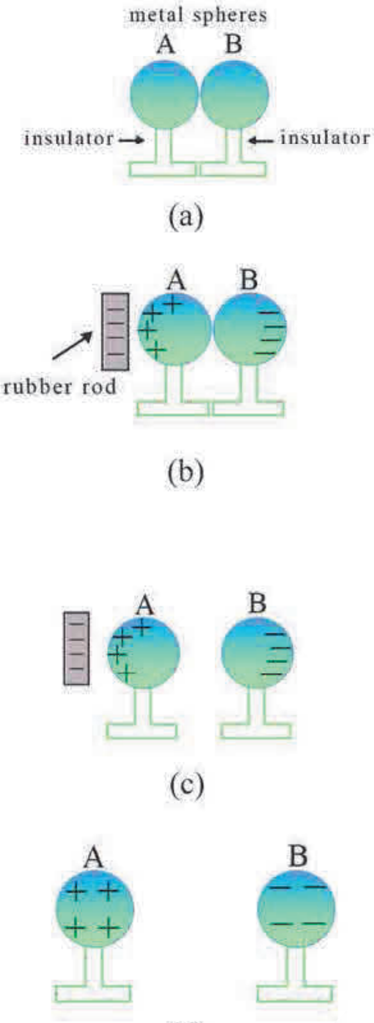
Step 4

Finally, the object A is taken away from sphere B, positive charges are uniformly distributed on the surface of the sphere.

Figure 9.4 Four steps in charging a single metal sphere by induction

(ii) Charging two metal spheres by induction

The method of charging a two-metal sphere system by induction using a negatively charged rubber rod is as follows:



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

Step 1

Two metal spheres of the same size A and B supported on insulating stands are in contact. These spheres can be considered as a single conductor. They are uncharged spheres.

Step 2

A negatively charged rubber rod is brought near (not touching) the sphere A. Since like charges repel the free electrons in both spheres move away from the rod and they collect at the right surface of sphere B. Now sphere A has excess positive charges, while sphere B has excess negative charges. These excess charges on the surfaces of A and B are called induced charges.

Step 3

Keeping the rubber rod in position, sphere B moves slightly from sphere A. The two spheres have opposite charges.

Step 4

Then the rubber rod is removed. Sphere A becomes a positively charged sphere and sphere B becomes a negatively charged sphere. Sphere A and B now have an equal number of opposite charges, the magnitude of the charge on the rubber rod remains unchanged.

Figure 9.5 Four steps in charging two metal spheres by induction

The law of conservation of electric charge is one of the fundamental laws. That is ‘The net electric charge in an isolated system remains constant’. The net charge is the algebraic sum of the charges in an isolated system.

For example, in the experiment on electrification by stroking the glass rod with a silk cloth, they together form an isolated system. There is no charge transfer between the surrounding and the isolated system. The net charge of isolated system remains constant before and after stroking.

Reviewed Exercise

- If the balloon near a wall is charged by rubbing with hair, the charged balloon will stick to a wall. Explain this phenomenon.

Key Words: electrification, induction

Some Applications of Static Electric Charges

There are several practical uses of static electricity in our daily life. Photocopier, electrostatic paint spraying, electrostatic precipitator etc., are based on static electric charges.

Photocopier

Basic operation of a photocopier is the attraction of charged toner (ink) to the region on the selenium coated drum that is oppositely charged.

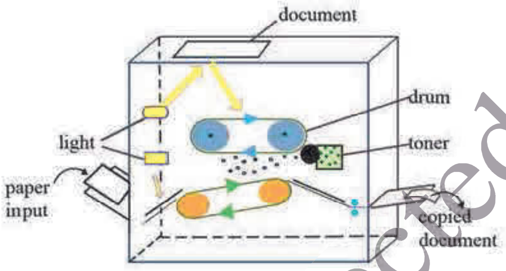


Figure 9.6 Static electricity used in a photocopier

Electrostatic paint spraying

The item (e.g., metal car frame) to be painted receives the negative charge from a negatively charged electrode. The droplets of paint emerge from the spray gun are positively charged. As the droplets all carry the same charge they repel and spread out forming a fine spray. The paint droplets are attracted to the surface of the frame. The paint is attracted statically to metal frame from every direction so there is no waste of spray paint.

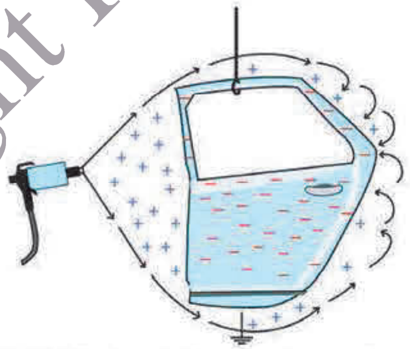


Figure 9.7 Electrostatic paint spraying

Electrostatic precipitator

The waste smoke, dust and fly ash are passed through a negatively charged mesh of wire in the chimney and the fly ash particles become negatively charged. Higher up the chimney these charged particles are attracted and stick to positively charged metal plate. The clean smoke is then released into the atmosphere.

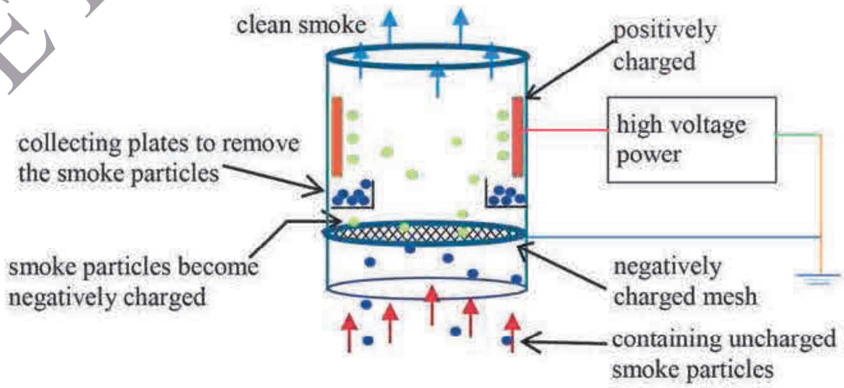


Figure 9.8 Electrostatic precipitator

Disadvantages of Static Electricity

In a scientific perspective, static electricity occurs when there is an imbalance of charges between two objects. Static electricity can build up as a result of collisions among the molecules in clouds. This can cause a huge spark to form between the ground and the cloud. This causes a lightning discharge, therefore, a flow of charge through the atmosphere.

As aircraft fly through the air, they can become charged with static electricity. A build-up of static charge is a potential danger when refuelling aircraft (or) vehicles. Fuel running through the pipes can provide the friction needed to create a static charge. To prevent this, aircraft are earthed with a conductor during refuelling.

Fuel tankers (bowsers) that transport fuel on roads must be earthed before any fuel is transferred, to prevent sparks causing a fire (or) explosion.Television screen and computer monitors become charged with static electricity when they are powered. These charges attract dust.

SUMMARY

Electrostatics is the study of electric charges at rest .
The two kinds of static electric charge are positive charge and negative charge.
Like charges repel and unlike charges attract.
The electric force between two charged objects is one of the fundamental forces of nature.
Charge is measured in coulomb (C).
The inner electrons that are tightly bound by nucleus are called **bound electrons**.
The electrons far away from the nucleus (or) the outer electrons are loosely bound and are called **free electrons**.
The substance which has plenty of free electrons is called a **conductor**.
The substance which has very few (or) no free electrons is called an **insulator.**
Some substances which contain a moderate amount of free electrons are called **semiconductors.**

EXERCISES

1. When a negatively charged sphere is brought near a suspended body, the suspended body is attracted to it. Is it correct to assume that the body is positively charged?
2. Choose the correct answer from the following.
   A. When an object contains an excess of electrons it has a positive charge.
   B. When an object contains a deficiency of electrons it has a positive electric charge.
   C. Since the nuclei of the atoms in an object are positively charged it has a positive electric charge.
   D. When the electrons of the atoms in an object are positively charged it has a positive electric charge.

3. Choose the correct answer from the following:

(i) The charge carrier of the conductor are _______.
(A. protons B. neutrons C. electrons)

(ii) _________ is a conductor.
(A. Wood B. Plastic C. Metal)

(iii) The SI unit of the electric charge is _________.
(A. coulomb B. ampere C. watt)

(iv) When an electron is removed from an atom, it becomes _______ ion.
(A. positive B. negative C. none of them)

(v) There is an electric current in conductor when electrons are _______.
(A. moving B. at rest C. none of them)

(vi) The magnitude of the charge of an electron is 1.6×10^{-19} C. A total of 10^4 electrons have been removed from an uncharged pith ball. Its charge now is _______.
(A. $+1.6 \times 10^{-15}$ C , B. $+1.6 \times 10^{-23}$ C , C. -1.6×10^{-15} C)

(vii) A glass rod becomes positively charged when it is rubbed with silk. The glass rod becomes charged because it _______ .
(A. gains protons, B. gains electrons, C. loses electrons)

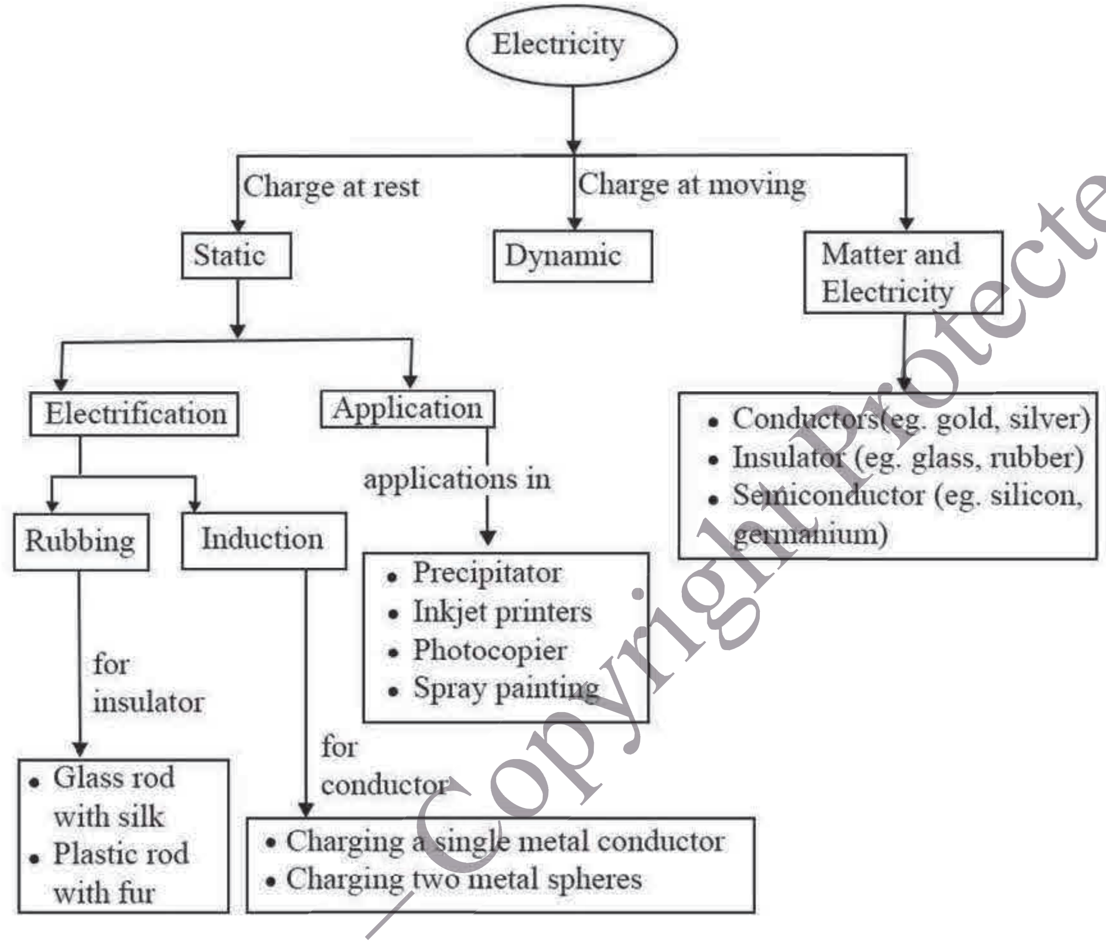
4. Match the following:

(i) Electron	A. positive charge
(ii) Proton	B. repel
(iii) Like charges	C. attract
(iv) Unlike charges	D. negative charge

5. Common static electricity involves charges ranging from nanocoulombs to microcoulombs. (a) How many electrons are needed to form a charge of – 2 nC? (b) How many electrons must be removed from a neutral object to have a net charge of +1 μC?

6. To start a car engine, the car battery moves 3.75×10^{20} electrons through the starter motor in one second. How many coulombs of charge were moved in that time?

CONCEPT MAP


Electricity
Charge at rest
Charge at moving
Static
Dynamic
Matter and Electricity
Electrification
Application
applications in
• Conductors(eg. gold, silver)
• Insulator (eg. glass, rubber)
• Semiconductor (eg. silicon, germanium)
Rubbing
Induction
• Precipitator
• Inkjet printers
• Photocopier
• Spray painting
for insulator
for conductor
• Glass rod with silk
• Plastic rod with fur
• Charging a single metal conductor
• Charging two metal spheres

CHAPTER 10

MAGNETISM

Magnetism is a phenomenon associated with magnetic field. A magnet has a magnetic field around it. A magnetic force arises due to interaction of magnetic fields.

Learning Outcomes

It is expected that students will

- analyse that the attraction between a specimen and a magnet is not sufficient enough to confirm that the specimen is a magnet.
- determine that all magnetised and unmagnetised materials consist of very tiny magnets.
- define a magnetic field in which magnetic effect can be detected and illustrate the pattern of magnetic field.
- differentiate the magnetic properties of iron and steel.
- demonstrate basic knowledge of magnets and their applications.

10.1 MAGNETS AND MAGNETIC MATERIALS

Magnets are the material which exhibit magnetic properties such as (1) attract magnetic materials (2) have two poles and (3) like poles repel, unlike poles attract.

Magnetic and Non-Magnetic Materials

Magnetite consists of an oxide of iron. This natural magnet attracts certain materials such as cobalt, nickel and some alloys such as steel. These materials are called magnetic materials. Materials such as brass, copper, wood and plastics that are not attracted by a magnet are called non-magnetic materials.

Any materials (such as magnetite) that is able to keep its magnetism for a long time is called a permanent magnet. Modern-day permanent magnets are usually made of steel (an alloy of iron) and special alloys such as alcomax and alnico which contain metals such as iron, nickel, copper, cobalt and aluminium. Another type of permanent magnet is ceramic magnet which is made from powders called ferrites (compounds of iron oxide with other metal oxides). However, these ceramic magnets are brittle.

Properties of Magnets

Besides exhibiting the property of attracting magnetic materials, all magnets also exhibit the following properties:

Magnetic Poles

Figure 10.1 shows what happens when we sprinkle some steel pins onto a magnet. Most of the pins are attracted to the two ends of the magnet.These two ends are called poles of the magnet.

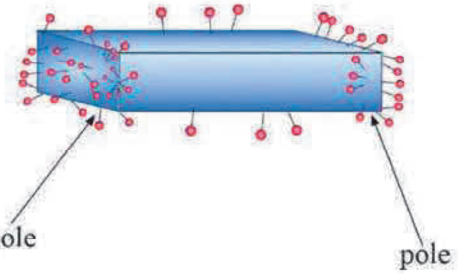


Figure 10.1 The pins show the positions of the poles of the magnet

North and South Poles

In Figure 10.2, the suspended bar magnet oscillates freely in air. When the suspended bar magnet comes to rest, one end always points towards the northern end of the Earth. This end of the magnet is thus called the north-seeking pole. Similarly, the other end of the magnet is called the south-seeking pole.

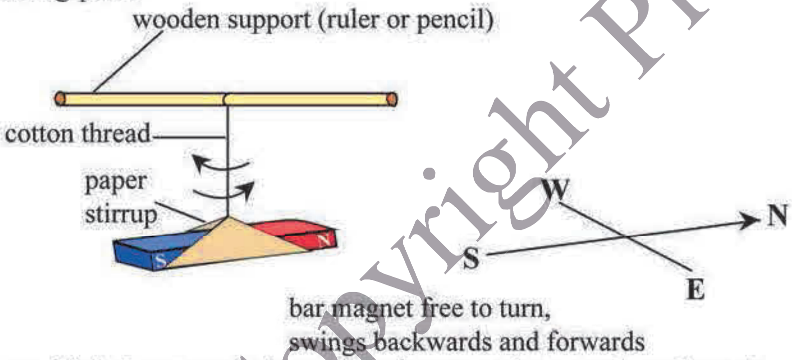


Figure 10.2 A suspended magnet always points north and south

The north-seeking pole and south-seeking pole of the magnet are usually referred to as simply the north pole (N-pole) and the south pole (S-pole) of the magnet.

Law of magnetic poles : Like poles repel and unlike poles attract.

A magnet can be used as a compass for navigation.

Magnetic Pole Strength and Magnetic Force

Magnetic pole strength is a measure of the strength of magnetic poles. When two magnetic poles are brought close to each other, one pole exerts certain force, either attractive (or) repulsive, on the other magnetic pole.

The force between two poles is directly propotional to the product of the pole strengths and inversely proportional to the distance squared between them.

Reviewed Exercise

- Give examples of magnetic materials and non-magnetic materials.

Key Words : magnet, pole, alloy, strength

10.2 THEORY OF MAGNETISM

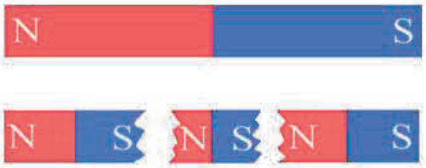


Figure 10.3 Each piece of the magnetised steel bar is a magnet

When we take a thin piece of magnetised steel bar and cut it into three smaller pieces. We will notice that every piece is a magnet with a N-pole and S-pole. Therefore, it would be reasonable to imagine that if we keep on cutting each piece of the magnet into even smaller pieces, they would still be magnetised (Figure 10.3). In other words, we can suppose that the original magnet is made up of lots of magnets all lined up with their N-poles pointing in same direction. This explains why the poles of the magnet are around the ends as shown in Figure 10.4 which illustrates a magnetised bar composed of tiny magnets. In the case of unmagnetised bar, we can imagine the 'tiny' magnets pointing in random direction as shown in Figure 10.5. The resulting magnetic effect of all the tiny magnets is then cancelled out and thus the bar is said to be unmagnetised.

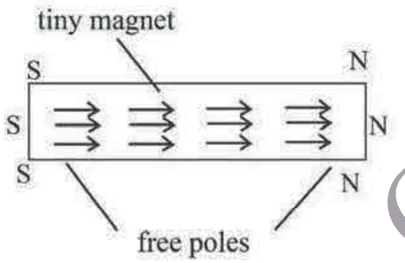


Figure 10.4 A magnetised bar

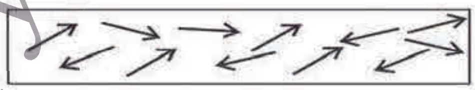


Figure 10.5 An unmagnetised bar

Both the magnetised materials (inclusive of magnets) and unmagnetised materials are made up of tiny magnets.

Key Words : magnetised, unmagnetised

10.3 MAGNETIC FIELDS

The magnetic field is a region where magnetic effects can be detected. Distribution of magnetic field can be visualized by the magnetic lines of force. The magnetic lines of force leave north pole and enter south pole. To show the pattern of a magnetic field around a bar magnet, we can sprinkle iron filings lightly on a paper, with a bar magnet underneath, and tapping the paper gently. Figure 10.6 shows the iron filings falling into a certain pattern which is the magnetic field pattern.

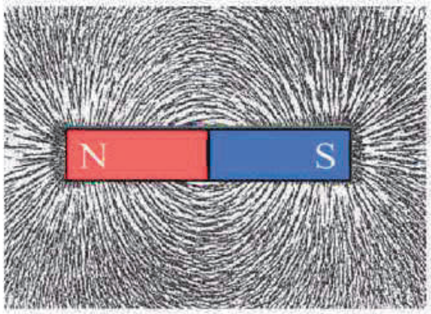
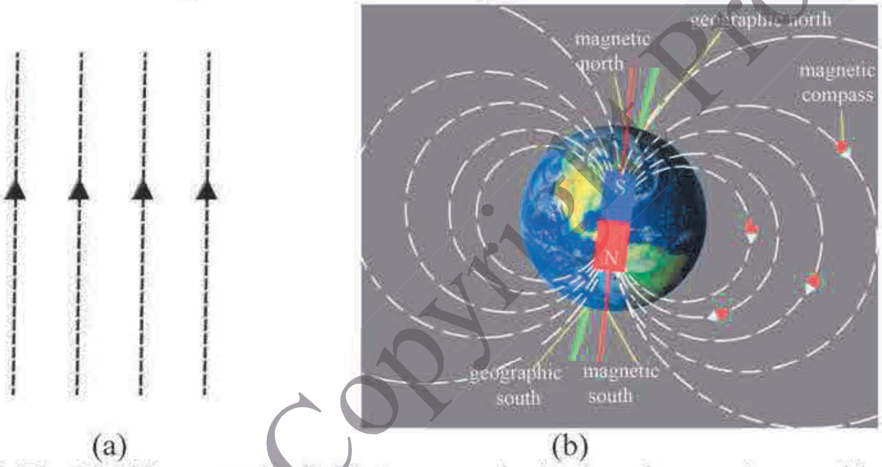


Figure 10.6 The magnetic field pattern of a bar magnet

The Earth's Magnetic Field

The Earth has a magnetic field. In other words, we can think of the Earth as having an imaginary bar magnet inside it with magnetic north and south poles as shown in Figure 10.7.



(a) (b)

Figure 10.7 (a) The Earth's magnetic field at any particular location can be considered as uniform (b) The Earth's magnetic field

The magnetic north lies somewhere in the sea in northern Canada but has been shifting slowly over the years. Magnetic fields can also be found in the interior of atoms and in stars and other celestial bodies.

A magnetic field has neither a starting point nor an end point because magnets never have a monopole in contrast to a point electric charge.

Reviewed Exercise

1. Describe an experiment to determine the positions of the poles of a bar magnet.
2. What experiment would you conduct to show the magnetic lines around a magnet?
3. Sketch on Figures, the magnetic field patterns formed between each pair of poles of the magnets.

(a)

(b)

Key Words : magnetc field, magnetic lines of force

10.4 MAGNETISATION AND INDUCED MAGNETISM

A process of making a magnetic material into a magnet is called magnetisation. Two types of magnetisation are (i) magnetisation by stroking and (ii) magnetisation using direct current.

Magnetisation by Stroking

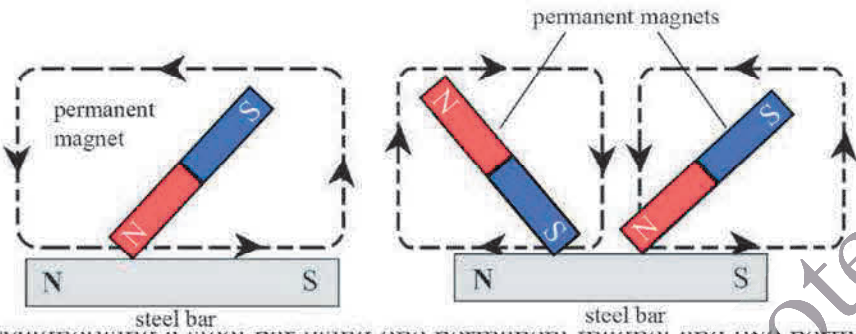


Figure 10.8 Magnetising a steel bar using one permanent magnet and two permanent magnets respectively

Figure 10.8 shows how to magnetise a steel bar using one permanent magnet and two permanent magnets respectively. The bar is stroked several times in the same direction along its length. The magnet (or) magnets must be lifted high above the bar between successive strokes. The end of the steel bar where the strokes finish always has the opposite polarity to that of the end of the stroking magnet in contact with it.

Magnetisation using Direct Current

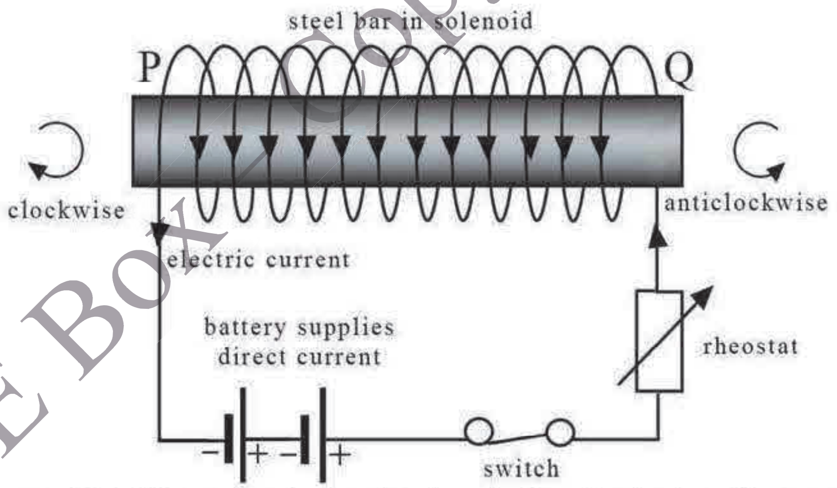


Figure 10.9 Magnetisation by the electrical method using direct current

The best way to make powerful magnets is to use the magnetic effect of an electric current. A steel bar is placed inside a solenoid and a direct current is passed through the solenoid. The solenoid produces a magnetic field that magnetises the steel bar permanently (permanent magnet). When the current through the solenoid is switched off, the steel bar stays magnetised. If an iron bar is placed instead of steel bar, the iron bar becomes magnetised temporarily (electromagnet). The polarities of the magnet produced depend on the direction of electric current.

Induced Magnetism

When a piece of unmagnetised magnetic material (such as iron or steel) is brought near to the pole of a permanent magnet, it is attracted to the magnet and becomes a magnet itself. This is called induced magnetism. The material is said to have magnetism induced in it. Figure 10.10 shows induced magnet being formed when a permanent magnet is brought near to a soft-iron bar.

Figure10.10 Permanent magnet brought near to soft-iron bar and soft-iron bar becomes an induced magnet

In Figure10.10 the north pole of the permanent magnet induces an S-pole in the near end of the soft iron while the far end of the soft iron becomes an N-pole. To check that the far end of the soft iron is a North-pole, hang two iron clips from the far end of the induced magnet as shown in Figure 10.11.

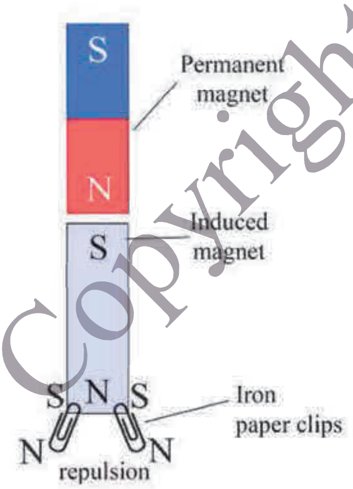
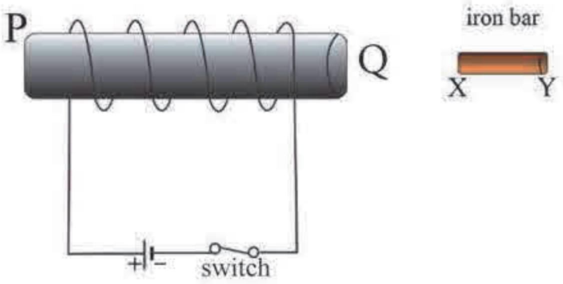


Figure10.11 The two iron clips become induced magnets and show repulsion between the far ends

Reviewed Exercise

- As shown in Figure when the switch is closed, which of the following pairs of poles is correct?



A. P is north and X is south.

B. P is south and X is south.

C. P is north and X is north.

D. P is south and X is north.

Key Words : stroking, electromagnet, permanent magnet

10.5 MAGNETIC PROPERTIES OF IRON AND STEEL

Iron is an element while steel is an alloy comprised of iron and carbon. Magnetic materials such as steel which are harder to magnetise but retain their magnetism longer are called hard magnetic materials. Magnetic materials such as iron or special alloys like mumetal alloy which are easier to magnetise but do not retain their magnetism very long are called soft magnetic materials.

The comparison of magnetic properties between iron and steel

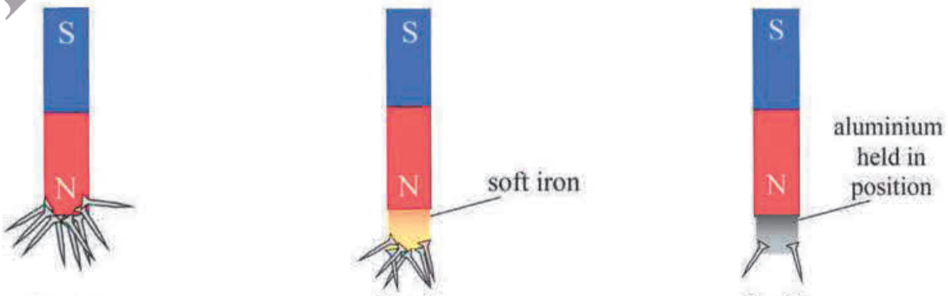
The magnetic properties of iron	The magnetic properties of steel
- can be easily magnetised and demagnetised	- is hard to magnetise and demagnetise than iron
- can be magnetised by a weak magnetic field	- requires a strong magnetic field to magnetise.
- retains its magnetism temporarily	- retains its magnetism permanently

Both types of magnetic materials have their own useful applications. For example, the hard magnetic materials such as steel are used in the making of permanent magnets, bar magnet, electric metre and loudspeaker. Soft magnetic materials (such as iron) are used in the cores of transformers, electromagnets, magnetic shielding, electric bell and magnetic relays.

Figure. 10.12 Magnetic shielding to store magnetically sensitive instruments such as watches

Reviewed Exercise

- Experiments were conducted to test the ability of a vertically held bar magnet to attract soft iron nails. The results are shown in Figure (a, b and c).



9 nails (a) 7 nails (b) 2 nails (c)

(i) What happened to the soft iron nails when they were placed in contact with the magnet?
(ii) Suggest why the soft iron in Figure (b) picked up almost as many nails as the magnet alone.
(iii) State and explain what would happened if the magnet was gently removed whilst the soft iron is still holding the 7 nails.
(iv) Although aluminium is a non-magnetic material, a few nails were attracted to it when it was placed at the end of the magnet suggest the reason for this.

Key Words : hard magnetic material, soft magnetic material, magnetic shield

SUMMARY

Magnets are the material which exhibit magnetic properties such as (1) attract magnetic materials (2) have two poles and (3) like poles repel, unlike poles attract.

Magnetite consists of an oxide of iron. This natural magnet attracts certain materials such as cobalt, nickel and some alloys such as steel. These materials are called **magnetic materials.** Materials such as brass, copper, wood and plastics that are not attracted by a magnet are called **non-magnetic materials.**

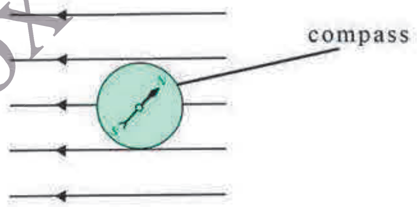
The magnetic field is a region where magnetic effects can be detected.

A process of making a magnetic material into a magnet is called **magnetisation.**

EXERCISES

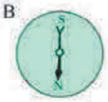
1. It can be confirmed that a metal bar is already magnetised if
   A. a magnet is attracted to it.
   B. an aluminium bar is attracted to it.
   C. both ends of a compass needle are attracted to the same end of the bar.
   D. one end of a compass needle is repelled by one end of the bar.

2. A small compass is placed in the uniform magnetic field as shown in Figure.

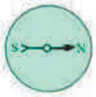


To which of the following directions will the compass needle point finally?

A

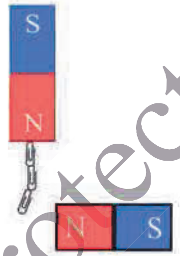

B


C


D


3. A metal bar PQ hung by a thin thread always comes to rest with end Q pointing North. Another bar XY of the same metal settles in no definite direction. Which of the following is true?
   A. End Q attracts end X but repels end Y.
   B. End Q repels end X but attracts end Y.
   C. End Q attracts both end X and end Y.
   D. End Q neither attracts nor repels end X and end Y.

4. Figure shows a strong magnet holding three paperclips. If a weaker magnet brought close to the end of the last clip as shown it will



   A. bend away from the magnet.
   B. bend towards the magnet.
   C. fall to the ground.
   D. stay still.

5. Which one of the following materials is most suitable for the core of an electromagnet?
   A. Steel
   C. Iron
   B. Brass
   D. Aluminium

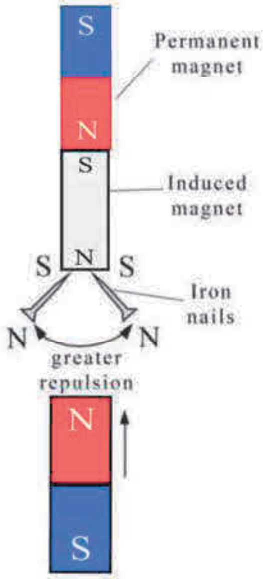
6. Which of the following materials is correctly described?

material	property	use
A. iron	not easily demagnetised	permanent magnet
B. iron	easily demagnetised	electro-magnet
C. steel	not easily demagnetised	electro-magnet
D. steel	easily demagnetised	permanent magnet

7. In which device is a permanent magnet used?
   A. An electric bell
   C. A plotting compass
   B. An electromagnet
   D. A relay

8. (a) Explain why a greater repulsion is occurred when a N-pole of bar magnet is brought towards the two far ends of the two iron nails for the given figure.

   (b) Suggest what would be observed when a S-pole of another bar magnet is brought towards the two far ends of the two iron-nails in Figure. Explain by an appropriate Figure.

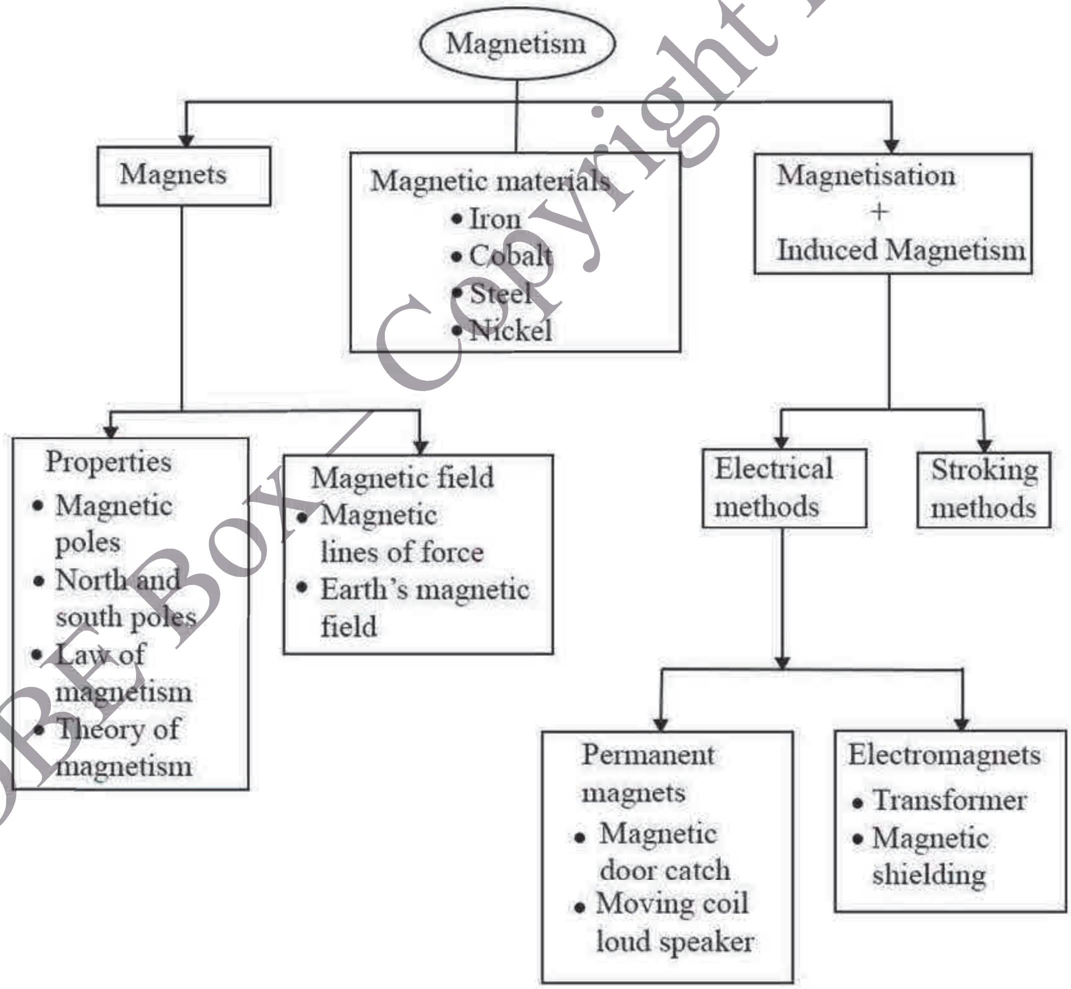


9. What are the main differences in the magnetic properties of soft iron and steel? How would you demonstrate them, experimentally? For each substance, name an instrument (or) piece of apparatus in which it is used because of its magnetic properties.

10. Describe briefly, with the help of simple diagrams if necessary,
    (a) how you would magnetise a steel rod PQ using a bar magnet so that P is a S-pole;
    (b) how an electric current can be used to make P a S-pole;
    (c) how you would check that the end P was a S pole after operations (a) and (b);
    (d) an electrical method to demagnetise PQ.

11. Give brief explanations of the following:
    (a) A piece of soft iron is attracted by a magnet.
    (b) A small bar magnet placed on top of a cork floating on water, does not move towards the north.
    (c) Two steel needles hanging from the lower end of a vertical bar magnet do not hang vertically in Figure.

CONCEPT MAP



CHAPTER 11

QUANTUM AND ATOMIC PHYSICS

All theories of physics developed before the arrival of relativity and quantum mechanics and any work derived from them are called classical physics. On the other hand, the theories derived from the basic principles of relativity and quantum mechanics which are two pillars of physics today, are called modern physics. The word modern was chosen since the main foundations of the two pillars of physics were laid in the first three decades of the twentieth century.

Learning Outcomes

It is expected that students will

- explain thermionic emission.
- describe the structure of a vacuum diode to visualize the flow of electrons from the filament to the plate.
- discuss blackbody radiation and quantum concept for microscopic particles.
- identify and explain some physical phenomena which could not be explained by classical Physics.
- describe the size of an atom and simplified models of atom.
- recognize the origin and evolution of the visible universe such as distance scales and sizes of astrophysical objects used in astrophysics.
- develop the competence in reasoning, comprehension and analysis of modern concepts of physics.

11.1 THERMIONIC EMISSION AND VACUUM DIODE

Thermionic Emission

The process by which, free electrons are emitted from the surface of a metal when external heat energy is applied, is called thermionic emission. Thermionic emission occurs in metals that are heated to a very high temperature. In other words, thermionic emission occurs, when a large amount of external energy in the form of heat is supplied to the free electrons in the metals.

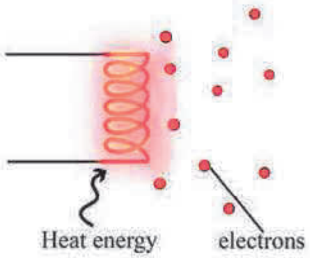


Figure 11.1 Thermionic emission

Vacuum Diode

Vacuum diode is the simplest form of vacuum tube. It consists of two electrodes, a cathode and an anode (or) plate. The cathode emits the free electrons by thermionic emission. It is an electron emitter. The anode collects the electrons. A vacuum diode is used as an AC (alternative current) to DC (direct current) converter.

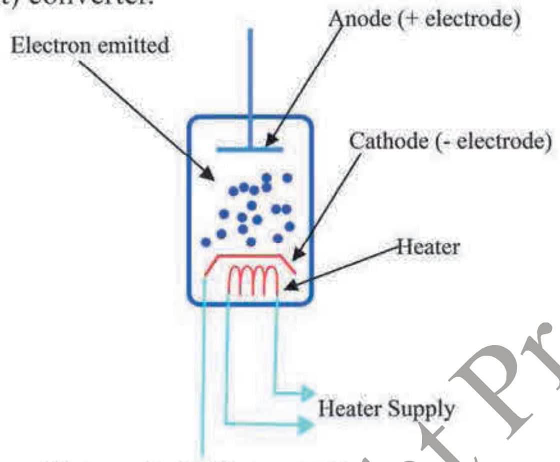


Figure 11.2 Vacuum diode

Some other vacuum tubes consisting of more than two electrodes are used as amplifiers. Nowadays, vacuum tubes are obsolete, having been replaced by transistors and semiconductor diodes.

Reviewed Exercise

1. Under what condition does the thermionic emission occur?
2. What is vacuum diode?

Key Words : thermionic emission, diode

11.2 BLACKBODY RADIATION AND THE CONCEPT OF PHOTON

At the end of 19th century scientists felt that all the laws of physics (which were known at that time) are enough to explain all the events occur in nature. It was believed that there are only two kinds of physical entities in nature, particles and radiation. All particles obey Newton's laws of motion and radiation obeys Maxwell's equations of electromagnetism. These laws are nowadays known as the laws of classical physics. Fortunately, physicists had performed some experiments which led to the development of modern concept of physics. The results of these experiments (such as blackbody radiation, photoelectric effect and Compton effect) could not be explained by the laws of classical physics.

Blackbody Radiation

A blackbody is a perfect radiator of light that absorbs and emits all radiation incident on it. Its light output depends on its temperature. The sun and stars emit radiation like a blackbody. A blackbody is physically realized by a small hole in the wall of a cavity radiator as shown in Figure 11.3.

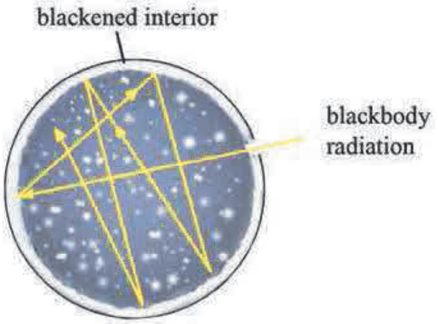


Figure 11.3 A blackbody represented by a small hole in the wall of a cavity

When a blackbody is heated, the radiation it emits is called blackbody radiation. Intensity of radiation is the energy emitted from unit area of the surface in one second. The graph drawn with the intensity of blackbody radiation against the wavelength at a given temperature is called blackbody spectrum as shown in Figure 11.4.

> The variation of intensity with the wavelength of this radiation at a given temperature gives a blackbody spectrum.

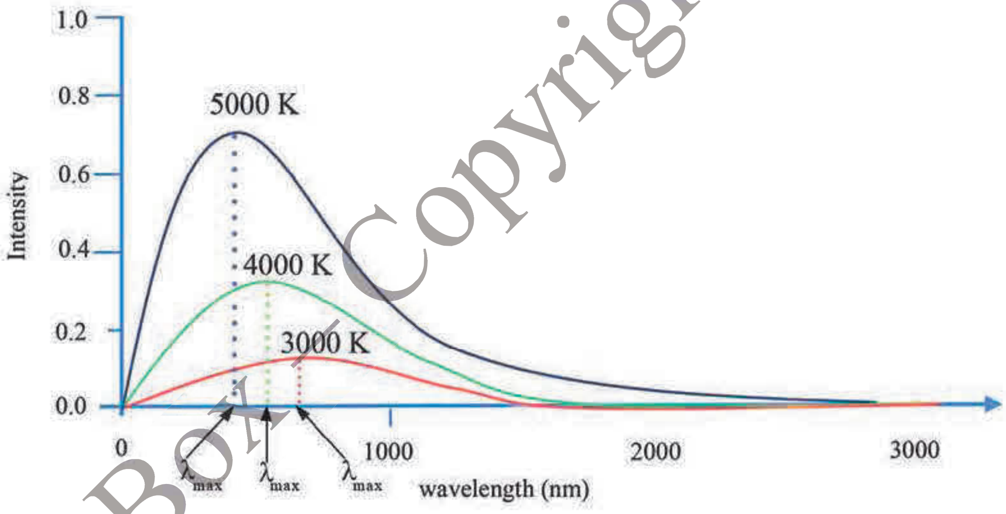


Figure 11.4 Intensity versus wavelength curve of the blackbody radiation at different temperatures

Two distinct features which can be observed from the blackbody spectrum are given as Wien's law and Stefan's law.

(i) Wien's Law

The wavelength at which maximum intensity occurs (λ_{max}) is inversely proportional to the absolute temperature of the blackbody. That is,

$$\lambda_{max} \propto \frac{1}{T}$$

It means that the higher the temperature, the shorter the wavelength λ_{max} .

(ii) Stefan Boltzmann's Law

The total emissive power of a blackbody (ε_0) is directly proportional to the fourth power of absolute temperature.

$$\varepsilon_0 = \sigma T^4, \ \sigma = \text{Stefan's constant}$$

It means that the higher the temperature, the higher the energy radiated.

These experimental observations of the blackbody spectrum could not be explained by classical physics.

Max Planck's Explanation of the Blackbody Radiation and the Concept of Photon

Detailed explanation of the blackbody radiation is given by Max Planck in 1900. Planck proposed that the radiation resulted from a large number of identical oscillators. Radiation is emitted (or absorbed) when an oscillator changes energy level. The emitted radiation from the oscillator can be thought of as particles called photons which carry energy. Although they are named particles they are chargeless and massless and travel with the speed of light *c*.
Plank assumed that the energy of a photon was proportional to its frequency, that is,

$$E \propto f \quad \text{(or)} \quad E = hf = h\frac{c}{\lambda}$$

where the constant h is the Planck constant and λ is the wavelength of the emitted radiation (photon).The numerical value of the Planck constant is $h = 6.626 \times 10^{-34}$ Js.

We see that photons with a long wavelength have *low* energy and photons with short wavelength have *high* energy. Suppose a certain amount of energy of a photon is given by hf and the number of photons is n, then the total energy is nhf. Since the number of photons must always be expressed as an integer, one can say that, for different values of n, the energy must have come in discrete amounts. That is, the simple quantum concept for energy of photons. A quantum of energy is the energy difference between the two allowed discrete values without ever reaching intermediate values. Quantized energies are discrete but not continuous.

Planck introduced the quantum concept as a modification of classical ideas that brought his theory into agreement with experimental observations.

Example (1) The energy of a single light photon is $E = hf$, the Planck's constant $h = 6.626 \times 10^{-34}$ Js, visible light wavelength is $\lambda = 0.5$ μm. Find the energy of the visible light. (1 eV = 1.6×10^{-19} J)

$$h = 6.626 \times 10^{-34}\ \text{Js}, \ \lambda = 0.5\ \mu\text{m}, \ c = 3 \times 10^8\ \text{m s}^{-1}$$

Since $c = f\lambda$,

$$E = hf = \frac{hc}{\lambda} = \frac{6.626\times10^{-34}\times3\times10^{8}}{0.5\times10^{-6}}$$

$$= 4 \times 10^{-19}\ \text{J}$$

$$= \frac{4\times10^{-19}}{1.6\times10^{-19}} = 2.5\ \text{eV}$$

Example (2) The energy of a certain incident ray is 4.14 eV. What is the frequency of this incident ray?

$$E = 4.14\text{ eV} = 4.14 \times 1.6 \times 10^{-19}\text{ J}$$

From $E = hf$, one has

$$f = \frac{E}{h} = \frac{4.14\times1.6\times10^{-19}}{6.626\times10^{-34}} \quad \text{(or)} \quad \frac{4.14}{4.14\times10^{-15}}$$

$$= 10^{15}\text{ Hz}$$

Reviewed Exercise

- Express the numerical value of the Plank constant h in terms of eVs.

Key Words : blackbody, spectrum, photon, quantized energy

11.3 MODELS OF ATOM

Thomson's Model

The discovery of the electron in 1897 prompted JJ. Thomson (1856 -1940) to suggest a model of the atom. He suggested that an atom might be a spherical volume of positive charge with electrons embedded inside it like currant in a bun (or) plums in a pudding. For this reason, Thomson's model is called the plum pudding model of the atom.

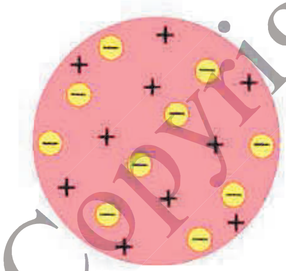


Figure 11.5 Thomson's plum pudding model of the atom
[https://www.electrical 4u.com/thomson-plum-pudding-model]

Rutherford's Model

Under the supervision of Ernest Rutherford (1871-1937), Hans Geiger and Ernest Marsden performed an important experiment in 1911. It produced results which could not be explained by Thomson's model.

In this experiment, a thin metal foil was bombarded with a beam of positively charged alpha particles. Most of the alpha particles passed straight through the foil, but a few were deflected from their original direction through very large angles. Some particles were even deflected backward as shown in Figure 11.6. The whole experiment setup is kept in the vacuum.

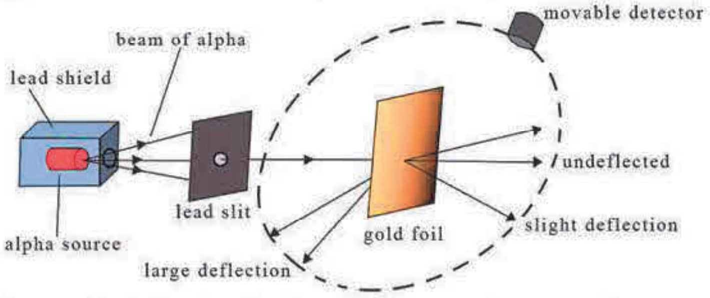


Figure 11.6 Rutherford's alpha scattering experiment

Such large deflections were completely unexpected on the basis of Thomson's model, in which positive charges are evenly distributed throughout the atom. Hence the positively charged alpha particles would never experience large enough repulsive force to cause large-angle deflections.

On the basis of his observation, Rutherford concluded that the atom must be largely empty space with all of its positive charges and most of its mass concentrated in a small region. This concentrated volume at the centre of the atom is called the nucleus. Negatively charged electrons are moving around the tiny nucleus as shown in Figure 11.7.

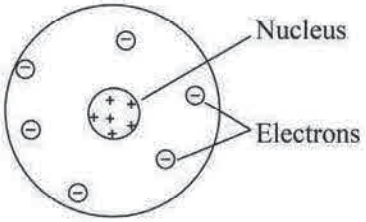


Figure 11.7 Rutherford's model of the atom

Bohr's Model

In 1913, Niels Bohr (1885 - 1962), a Danish Physicist, proposed a new model of the atom by applying the quantum theory. In Bohr's model, the electrons move in circular orbits around the nucleus. The electric force between the positively charged proton inside the nucleus and the negatively charged electron holds the electron in orbit. However, only certain orbits are allowed in this model. The electron is never found between the allowed orbits. However it can jump from one orbit to another. Bohr assumed that the atom does not emit energy in the form of radiation when the electron is in an allowed orbit. Hence the total energy of the atom remains constant and it resolved the instability of the atom which is a difficulty of the Rutherford model.

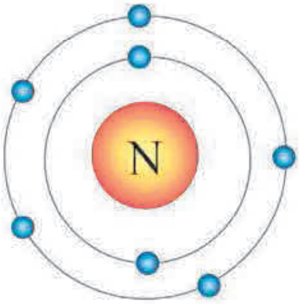


Figure 11.8 Bohr's model of the atom

Reviewed Exercise

- Discuss the essential differences among Thomson's model, Rutherford's model and Bohr's model of an atom.

Key Words : alpha particle, nucleus, electron, proton

11.4 ATOMIC STRUCTURE

All matter is made of atoms. Atoms are too tiny to be seen with any ordinary microscope. Atoms are composed of smaller particles called electrons, protons and neutrons. There is a central nucleus made up of protons and neutrons. Around this, electrons orbit at high speed in allowed orbits. A simple model of the atom is illustrated in Figure 11.9.

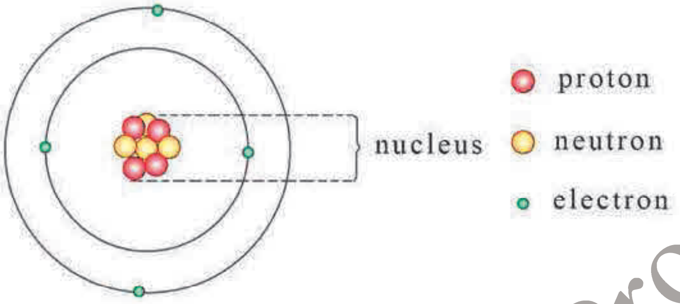


Figure 11.9 An illustration of an atom

Protons have a positive charge and electrons have an equal negative charge, while the neutrons are neutral. An atom has the same number of electrons as protons, so its total charge is zero. Thus, atom as a whole is neutral. Together, protons and neutrons are known as nucleons. Protons and neutrons have similar masses and electrons are the lightest. Protons and neutrons are about 1800 times more massive than an electron, so all of an atom's mass is concentrated in its nucleus. Electrons are held in orbit by the Coulomb attractive force of the nucleus. Protons and neutrons are bound tightly together in the nucleus by the strong nuclear force. The properties of these particles are summarized in Table 11.1.

Table 11.1 Comparison of proton, neutron and electron of an atom in terms of charge and mass

Particle	Position	Charge (C)	Mass (kg)
Proton	in the nucleus	$+1.6 \times 10^{-19}$	1.67×10^{-27}
Neutron	in the nucleus	0	1.67×10^{-27}
Electron	orbiting nucleus	-1.6×10^{-19}	9.11×10^{-31}

Atomic Number

All materials are made from about 100 basic substances called elements. An atom is the smallest piece of an element. The atomic number of an element tells us how many protons (or) electrons are in an atom of that element. It is written as symbol Z. Each element has its own unique atomic number. The atomic number is sometimes called the proton number. The chemical properties of an element is determined by the number of electrons in the atom, that is atomic number.

Mass Number

The total number of protons and neutrons in the nucleus of an atom is called the mass number (or) the nucleon number. The mass number of an element is given the symbol A.

Symbol of Atom

An atom of an element with atomic number Z and the mass number A is represented by its chemical symbol X as ${}^{A}_{Z}\mathrm{X}$.

Mass number = Number of neutrons + Number of protons = Number of nucleons
Number of neutrons = Mass number – Number of Proton
= Mass number – Atomic Number
Number of neutrons = $A - Z$

Elements and isotopes

Although atomic number of an element does not change, atoms of the same element can have different mass numbers. This is because the number of neutrons in a particular element can vary.

Atoms that have the same atomic number but different neutron numbers (and thus different mass numbers) are called isotopes. They have identical chemical properties, although their atoms have different masses. Most elements are a mixture of two (or) more isotopes.

Hydrogen has three isotopes protium or hydrogen (${}^{1}_{1}\mathrm{H}$), deuterium (${}^{2}_{1}\mathrm{H}$) and tritium (${}^{3}_{1}\mathrm{H}$).

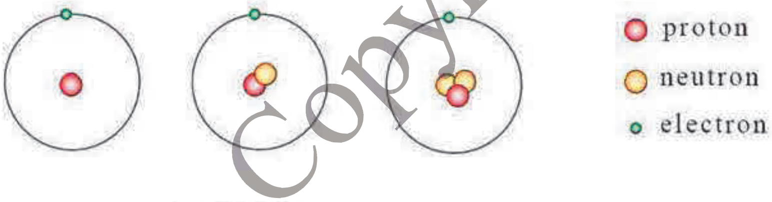


Figure 11.10 Three isotopes of hydrogen

Reviewed Exercise

1. Is it possible for the atom of an element to have one electron, one proton and no neutron? If so, name the element.
2. Which force holds the electrons and nucleus of an atom to form an atom?

Key Words : atomic number, mass number, isotope

11.5 THE STRUCTURE AND EVOLUTION OF THE VISIBLE UNIVERSE

The part of the universe which we can see is termed the visible universe. The actual universe might be bigger than the visible universe. The part we can see is determined by the age of the universe. For example, suppose that the universe is 1.38×10^{10} years old, as indicated by currently available astrophysical measurements. That means the farthest away from the earth that we can see, in any direction, is 4.65×10^{10} light year, i.e. the distance light can travel in the time since the universe was formed.

To learn the fundamentals of the universe one needs to study astronomy, astrophysics and cosmology which are three closely related subjects. Differences come from the domains and goals of the study of the three fields.

Astronomy is a natural science that deals with the study of celestial objects, which are any natural bodies outside of the earth's atmosphere. Examples are the Moon, the Sun, planets, stars, comets, nebulae, star clusters and galaxies, etc.

Astrophysics is the branch of astronomy that deals with the physics of the universe, including the physical properties of celestial objects, as well as their interactions and behavior. Among the objects studied are galaxies, stars, planets, exoplanets, the interstellar medium and the cosmic microwave background.

Cosmology studies the universe as a whole and its phenomena at largest scales. The difference between Astrophysics and Cosmology is the domain and scale of the study.

A Brief Outline of the Universe

The Earth, our planet is part of the solar system that contains eight planets and the Sun. The Sun is a star and there are many others like it in the universe. The closest star to our own is called Proxima Centauri, together with approximately 10^{11} other stars they make up the Milky Way.

The Milky Way is one of about 10^{11} galaxies in the visible universe. Therefore, the visible universe consists of roughly 10^{22} stars. Galaxies cluster into groups; our group is labeled the Local Group and contains about 30 galaxies. The main force holding all of these systems together is gravity.

Units in Measuring Astronomical Distances

Astronomers have created units of measurement for astronomical distances. One of these units is called an Astronomical Unit (AU), the mean distance between the Earth and the Sun, that is, 1.496×10^8 km. The light year is an another astronomical unit for measuring large distances. The light year (ly) is the distance travelled by light in a vacuum in one year. One simply has,

$$1\ ly = 60\times 60\times 24\times 365\times 3\times 10^{8} = 9.46\times 10^{15}\ \text{m} = 9.46\times 10^{12}\ \text{km}$$

One parsec (pc) is the distance to a star that subtends an angle of 1 arc sec (arc second) at an arc length of 1 AU.

Through trigonometry, the distance SD (Figure 11.11) is calculated as follows.

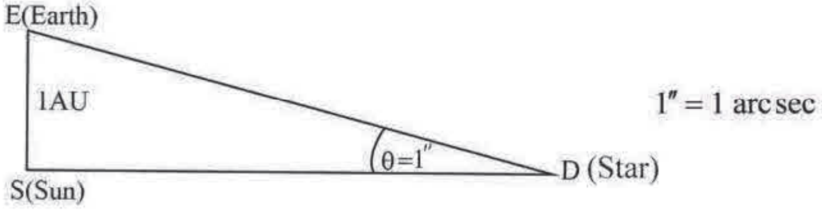


Figure 11.11 An Astronomical triangle

From the above figure , one gets

$SD = \dfrac{ES}{\tan\theta}$ since the tangent θ is very small, one has tangent θ , and $\theta = 1''$.

It has been known that 1 degree = $\dfrac{\pi}{180}$ = 60 × 60 = 3600 arc sec

1 arc sec = $\dfrac{\pi}{60\times60\times180}$

then SD can be written as

$$SD \approx \frac{ES}{1''} = \frac{1\ AU}{\dfrac{1}{60\times60}\times\dfrac{\pi}{180}} = \frac{648\ 000}{\pi} AU \approx\ 206\ 264.81\ AU.$$

$$SD = 1pc = 206\ 264.81\times1.496\times10^{8}$$

$$= 3.08\times10^{13}\,km$$

Table 11.2 Comparison of measuring units for astronomical distances

Astronomical Unit	AU	1 AU = 1.496×10^{8} km
light year	*ly*	1 *ly* = 9.46×10^{12} km
parsec	pc	1 pc = 3.08×10^{13} km
		1 pc = 3.26 *ly* 1 pc = 206 265 AU

Evolution of the Universe

Astrophysicists and astronomers have theorized that the universe must have originated at a single point of infinite density and finite time then began to expand. This is known as the Big Bang theory. After the initial expansion, the theory maintains that the universe cooled sufficiently to allow the formation of subatomic particles, and later simple atoms. Giant clouds of these primordial elements later coalesced through gravity to form stars and galaxies. This all began roughly 13.8 billion years ago, and is thus considered to be the age of the universe. Scientists have constructed through the testing of theoretical principles and extensive experiments a timeline of events that began with the Big Bang up to the current state of cosmic evolution. These experiments involve astronomical studies that have observed the deep universe.

Table 11.3 Physical Data of the Visible Universe

Diameter	8.8×10^{26} m (28.5 Gpc or 93 G*ly*)
Volume	4×10^{80} m^{3}
Mass (ordinary matter)	4.5×10^{51} kg
Density (of total energy)	9.9×10^{-27} kg m^{-3} (equivalent to 6 protons per cubic meter of space)
Age	1.38×10^{10} years (or) 13.799 billion years
Average temperature	2.725 48 K
Contents	• Ordinary matter (4.9%) • Dark matter (23%) • Dark energy (72%)

Reviewed Exercise

- What is the light year?

Key Words : astronomy, astrophysics, cosmology

SUMMARY

Blackbody Radiation

A blackbody is a perfect radiator of light that absorbs and re-emits all radiation incident on it. Its light output depends on its temperature. The sun and stars emit radiation like a blackbody.

Wien's Law is the wavelength at which maximum intensity occurs (λ_{max}) is inversely proportional to the absolute temperature of the blackbody.

Stefan's Law is the total amount of energy emitted by a blackbody is proportional to the fourth power of absolute temperature.

Astronomy is a natural science that deals with the study of celestial objects, which are any natural bodies outside of the earth's atmosphere. Examples are the Moon, the Sun, planets, stars, comets, nebulae, star clusters and galaxies.

Astrophysics is the branch of astronomy that deals with the physics of the universe, including the physical properties of celestial objects, as well as their interactions and behavior. Among the objects studied are galaxies, stars, planets, exoplanets, the interstellar medium and the cosmic microwave background.

Cosmology studies the universe as a whole and its phenomena at largest scales. The difference between Astrophysics and Cosmology is the domain and scale of the study.

The Visible Universe

The part of the universe which we can see is termed the visible universe. The actual universe might be bigger than the visible universe.

EXERCISES

Choose the correct answer for the following.

1. The main force responsible for the formation of the universe is:
   A. gravity C. magnetic force
   B. frictional force D. electrical force
2. The approximate age of the universe is:
   A. 1 billion years old and 14 days C. 140 billion years old
   B. 14 billion years old D. 13.7 billion years old
3. The first objects to form in the solar system were
   A. atoms C. comets
   B. stars D. planets

4. Which of the following correctly lists the structures in space from smallest to largest?
A. Stars, Galaxy, Universe, solar system C. Stars, solar system, Universe, Galaxy
B. Stars, solar system, Galaxy, Universe D. Stars, Universe, Solar system, Galaxy

5. Our galaxy, the Milky Way, has a pinwheel shape, what type of galaxy is it?
A. elliptical C. irregular
B. fun D. spiral

6. Which of the following is the best estimate of the number of stars in a typical galaxy?
A. hundreds C. millions
B. thousands D. billions

7. Which of the following is the best estimate of the number of galaxies in the universe?
A. hundreds C. millions
B. thousands D. billions

8. A light year measures
A. the distance it takes light to travel in 1 year C. the speed of light
B. the distance between stars D. the wavelength of visible light

9. Which of the following is the smallest?
A. the earth C. a galaxy
B. the universe D. the sun

10. Which of the following is the largest?
A. the earth C. a galaxy
B. the universe D. the sun

11. What is the frequency of a photon whose energy is 66.3 eV?
$\left(1\text{eV} = 1.6\times10^{-19}\text{J},\ h = 6.625\times10^{-34}\text{Js}\right)$

12. Which subatomic particle has a negative charge?

13. Which subatomic particle has a positive charge?

14. Which subatomic particle is a neutral?

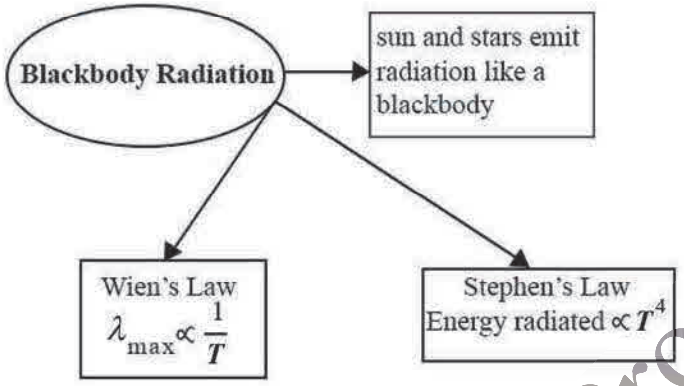
15. What is thermal radiation? How does it differ from other form of electromagnetic radiation?

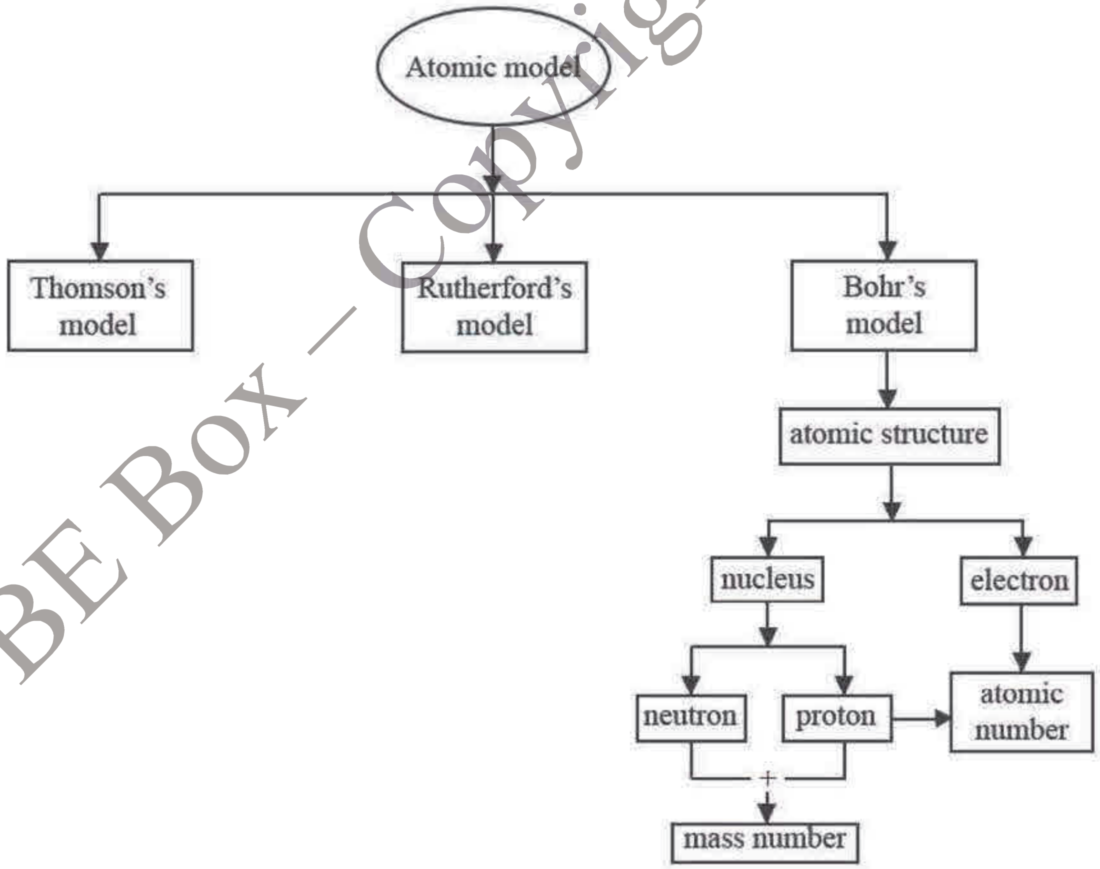
16. An atom contains electrons, protons, and neutrons. Which of these particles
(a) are outside the nucleus (b) are uncharged (c) have a negative charge (d) are nucleons
(e) are much lighter than the others?

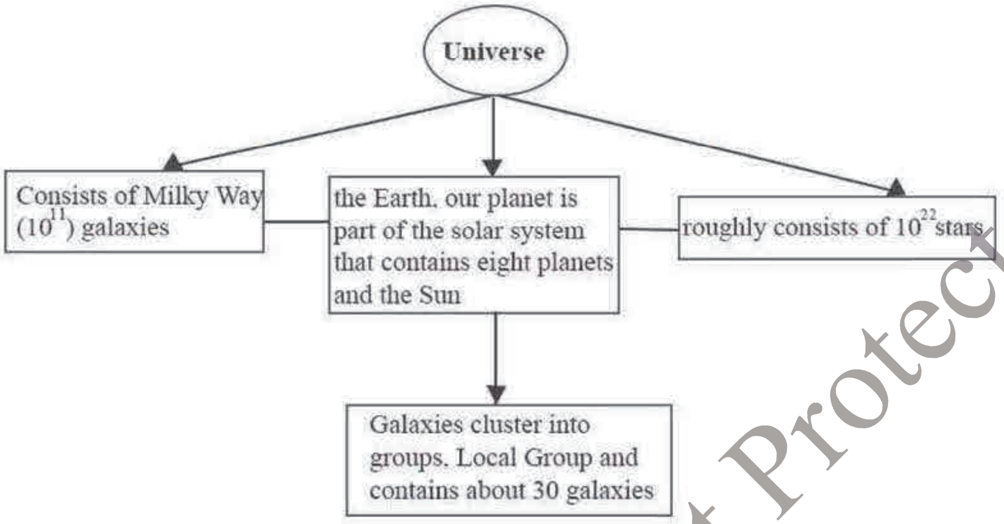
17. An aluminium atom has an atomic number of 13 and a mass number of 27. How many (a) protons (b) electrons (c) neutrons does it have?

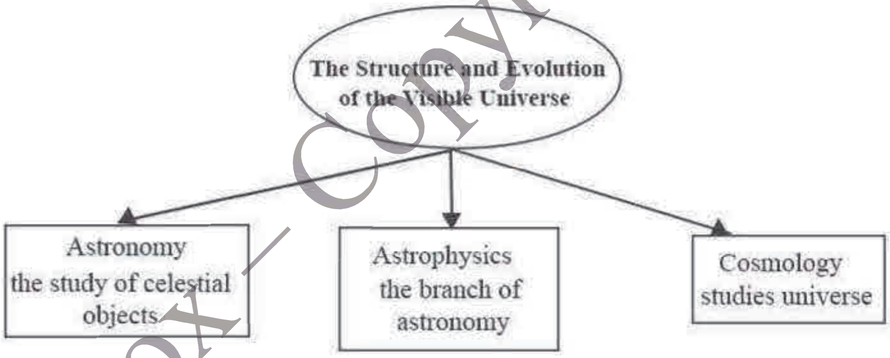
18. Chlorine is a mixture of two isotopes, with mass numbers 35 and 37. What is the difference between the two types of atom?

CONCEPT MAP


Blackbody Radiation
sun and stars emit radiation like a blackbody
Wien's Law
$\lambda_{max} \propto \frac{1}{T}$
Stephen's Law
Energy radiated $\propto T^4$


Atomic model
Thomson's model
Rutherford's model
Bohr's model
atomic structure
nucleus
electron
neutron
proton
+
atomic number
mass number


Universe
Consists of Milky Way (10^{11}) galaxies
the Earth, our planet is part of the solar system that contains eight planets and the Sun
roughly consists of 10^{22} stars
Galaxies cluster into groups, Local Group and contains about 30 galaxies


The Structure and Evolution of the Visible Universe
Astronomy the study of celestial objects
Astrophysics the branch of astronomy
Cosmology studies universe

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APPENDIX

CONVERSION FACTORS

Length

1 metre (m)	= 100 cm = 1 000 mm	1 foot (ft)	= 30.48 cm = 0.304 8 m
	= 39.4 in		
	= 3.28 ft	1 inch (in)	= 0.083 3 ft
1 centimetre (cm)	= 0.394 in		= 2.54 cm
1 kilometre (km)	= 1 000 m	1 mile (mi)	= 1.61 km
	= 0.621 4 mi		= 5 280 ft

Area

1 m^2	= 10^4 cm^2	1 ft^2	= 0.092 9 m^2
	= 1.55×10^3 in^2		= 929 cm^2
	= 10.76 ft^2		= 144 in^2
1 cm^2	= 10^{-4} m^2	1 in^2	= 6.452 cm^2
	= 0.155 in^2		

Volume

1 m^3	= 10^6 cm^3	1 ft^3	= 0.028 3 m^3
	= 35.3 ft^3		= 28.3 litres
	= 6.10×10^4 in^3		= 7.48 gal
1 in^3	= 16.39 cm^3	1 liter	= 1 000 cm^3 = 10^{-3} m^3
			= 0.035 1 ft^3
			= 61 in^3

Mass

1 kilogram (kg)	= 0.068 5 slug (sl)	1 sl	= 14.57 kg
	= 1 000 g	1 lb	= 454 g
			= 0.454 kg

Time

1 day	= 1.44×10^3 min	= 8.64×10^4 s	
1 year	= 8.76×10^3 h	= 5.26×10^6 min	= 3.15×10^7 s

Angle

1 radian (rad)	= 57°18′ =57.30°	1°	= 0.01745 rad

Greek Alphabet

Α	α	Alpha	Ν	ν	Nu
Β	β	Beta	Ξ	ξ	Xi
Γ	γ	Gamma	Ο	ο	Omicron
Δ	δ	Delta	Π	π	Pi
Ε	ε	Epsilon	Ρ	ρ	Rho
Ζ	ζ	Zeta	Σ	σ	Sigma
Η	η	Eta	Τ	τ	Tau
Θ	θ	Theta	ϒ	υ	Upsilon
Ι	ι	Iota	Φ	ϕ	Phi
Κ	κ	Kappa	Χ	χ	Chi
Λ	λ	Lambda	Ψ	ψ	Psi
Μ	μ	Mu	Ω	ω	Omega

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Angle

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Greek Alphabet

Α	α	Alpha	Ν	ν	Nu
Β	β	Beta	Ξ	ξ	Xi
Γ	γ	Gamma	Ο	ο	Omicron
Δ	δ	Delta	Π	π	Pi
Ε	ε	Epsilon	Ρ	ρ	Rho
Ζ	ζ	Zeta	Σ	σ	Sigma
Η	η	Eta	Τ	τ	Tau
Θ	θ	Theta	ϒ	υ	Upsilon
Ι	ι	Iota	Φ	ϕ	Phi
Κ	κ	Kappa	Χ	χ	Chi
Λ	λ	Lambda	Ψ	ψ	Psi
Μ	μ	Mu	Ω	ω	Omega

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