10.4 SPHERICAL MIRRORS

The most commonly used type of curved mirror is the spherical mirror. The reflecting surface of such mirrors can be considered to form a part of the surface of a sphere. Such mirrors, whose reflecting surfaces are spherical, are called spherical mirrors.

The reflecting surface of a spherical mirror may be curved inwards or outwards. A spherical mirror, whose reflecting surface is curved inwards (faces towards the centre of the sphere), is called a concave mirror [Fig. 10.1 (a)]. A spherical mirror whose reflecting surface is curved outwards, is called a convex mirror [Fig. 10.1 (b)]. The schematic representation of these mirrors (back of the mirror is shaded) is shown in Fig. 10.1.

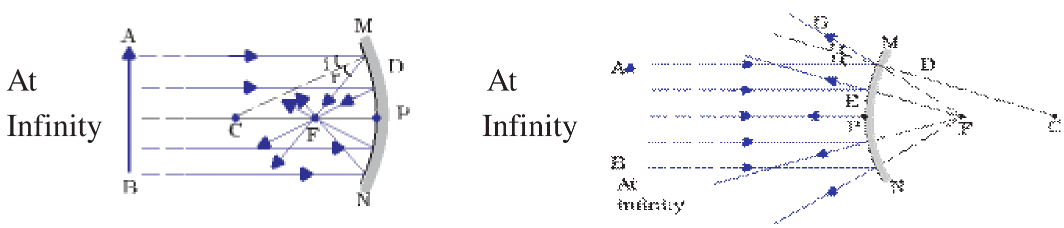
(a) Concave mirror (b) Convex mirror

Figure 10.1 **Schematic representation of spherical mirrors**

Now one analogy with spoon can be drawn here. The surface of the spoon curved inwards can be approximated to a concave mirror and the surface of the spoon bulged outwards can be approximated to a convex mirror.

Now it is important to know the terms commonly used in discussions about spherical mirrors. The centre of the reflecting surface of a spherical mirror is a point called the pole. It lies on the surface of the mirror. The pole is usually represented by the letter P.

The reflecting surface of a spherical mirror forms a part of a sphere. This sphere has a centre. This point is called the centre of curvature of the spherical mirror. It is represented by the letter C. Please note that the centre of curvature is not a part of the mirror. It lies outside its reflecting surface. The centre of curvature of a concave mirror lies in front of it. However, it lies behind the mirror in case of a convex mirror. You may note this in Fig.10.2 (a) and (b). The radius of the sphere of which the reflecting surface of a spherical mirror forms a part, is called the radius of curvature of the mirror. It is represented by the letter R. You may note that the distance PC is equal to the radius of curvature. Imagine a straight line passing through the pole and the centre of curvature of a spherical mirror. This line is called the principal axis. Remember that principal axis is normal to the mirror at its pole.



(a) (b)

Figure 10.2 **(a) Concave Mirror (b) Convex Mirror**

Figure 10.2 (a) demonstrates that a number of rays parallel to the principal axis are falling on a concave mirror. Observe the reflected rays. They are all meeting/ intersecting at a point on the principal axis of the mirror. This point is called the principal focus of the concave mirror. Similarly, Fig. 10.2 (b) reflects that the reflected rays appear to come from a point on the principal axis. This point is called the principal focus (F) of the convex mirror. The distance between the pole and the principal focus of a spherical mirror is called the focal length (f).

The reflecting surface of a spherical mirror is by and large spherical. The surface, then, has a circular outline. The diameter of the reflecting surface of spherical mirror is called its aperture. In Fig.10.2, distance MN represents the aperture. Here only such spherical mirrors are discussed whose aperture is much smaller than its radius of curvature. For spherical mirrors of small apertures, the radius of curvature (R) is found to be equal to twice the focal length. We put this as $R = 2f$. This implies that the principal focus of a spherical mirror lies midway between the pole and centre of curvature.

Check Your Progress-1

Note: (a) Answer the questions given below.

(b) Compare your answers with those given at the end of this lesson.

1. Fill in the blanks:

   (a) A spherical mirror, whose reflecting surface is curved inwards, that is, faces towards the centre of the sphere, is called a ___________.

   (b) A spherical mirror whose reflecting surface is curved outwards, is called a ______________.

   (c) The diameter of the reflecting surface of spherical mirror is called its ___________.

   (d) If the radius of curvature of a spherical mirror is 10 cm. Its focal length is ___________.

2. Choose the correct option for the following questions:

A. The centre of the reflecting surface of a spherical mirror is a point called the _______________.

   (a) Focus

   (b) Pole

   (c) Curvature

   (d) Focal length

B. The principal focus of a spherical mirror lies ___________________.

   (a) midway between the pole and centre of curvature

   (b) at the pole

   (c) at the centre of curvature

   (d) far beyond the centre of curvature

10.5 REPRESENTATION OF IMAGES FORMED BY SPHERICAL MIRRORS USING RAY DIAGRAMS

Diagrams are used to depict the image formation by tracing the path of light rays i.e. incident rays and reflected rays. They are drawn in order for anyone to view a point on the image of an object. These ray diagrams depend on the position of the object.

10.5.1 Ray Diagrams for a Concave Mirror

For a concave mirror, there are six possible positions (Fig 10.3 to Fig 10.8) where the object can be positioned and an image is formed:

a. Object is positioned at infinity

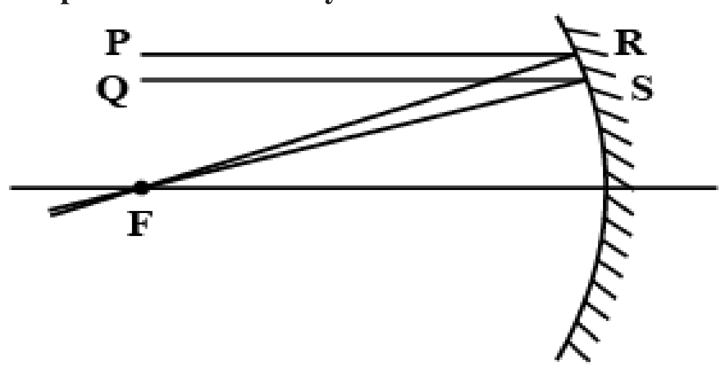


Figure 10.3: **Object is positioned at infinity**

When the object is placed at infinity, rays PR and QS parallel to the axis are reflected from points R and S respectively. Rays PR and QS intersect each other and get converged at the principal focus (F). And since when the object is placed at infinity, the properties of the images formed are highly diminished, point sized and real and inverted.

b. Object is positioned between infinity and Center of Curvature (C)

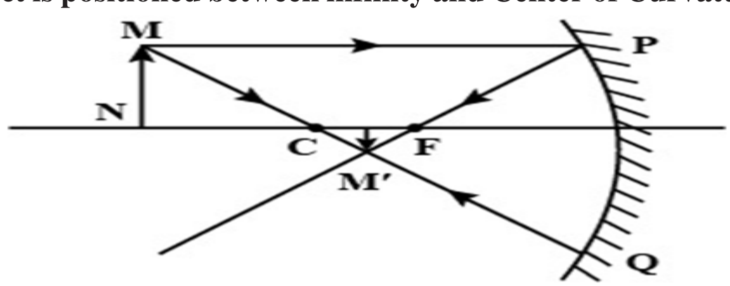


Figure 10.4: **Object is positioned between infinity and center of curvature (C)**

Here the object MN is placed between infinity and center of curvature (C) of a concave mirror, then a ray MP parallel to the principal axis and another ray MQ that pass through the center of curvature (C) intersect each other at M' after reflection between focus (F) and center of curvature (C). Therefore, the properties of the images formed here are that the image formation is between principal focus (F) and center of curvature (C), the image formed is diminished and real and inverted.

c. Object is positioned at Center of Curvature (C)

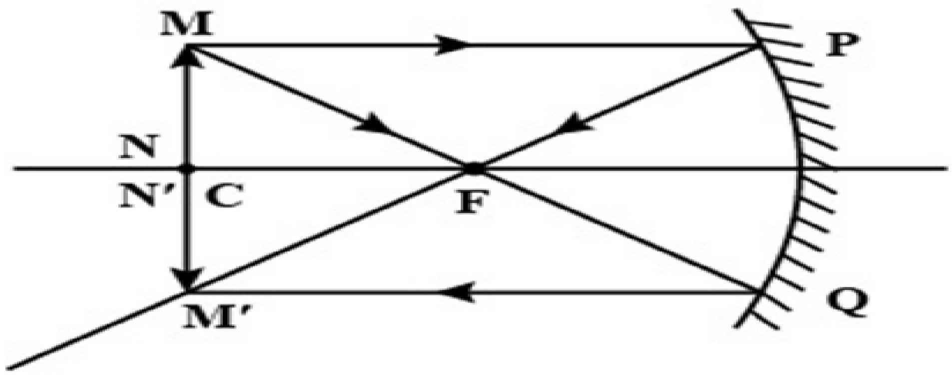


Figure 10.5: **Object is positioned at center of curvature (C)**

When the object MN is placed the at the center of curvature (C), then a ray MP parallel to the principal axis and another ray MQ that passes through the principal focus (F) after reflection, intersect each other at point M' right below where the object MN is positioned. Hence, the properties of the images formed in this case are that image is formed at the center of curvature, the image is the same size as the object and images are real and inverted.

d. Object is positioned between the center of curvature (C) and principal focus (F)

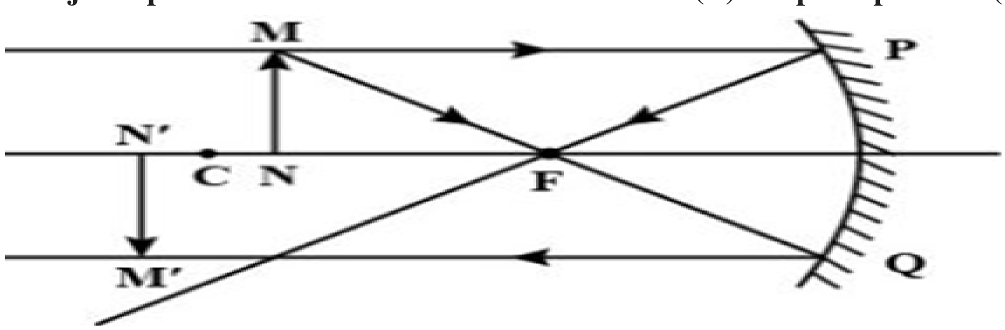


Figure 10.6: **Object is positioned between the center of curvature (C) and principal focus (F)**

Object MN is placed between the center of curvature (C) and principal focus (F), then the ray MP parallel to the principal axis and another ray MQ passing through principal focus (F) intersect each other beyond the center of curvature (C) at point M’. Hence, the properties of the images formed here are that the image is formed beyond the center of curvature (c), and the image is real and inverted.

e. Object is positioned at Principal Focus (F)

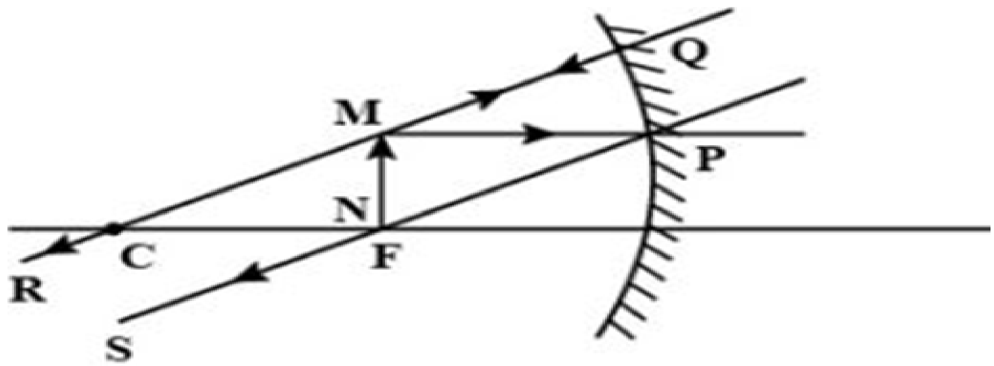


Figure 10.7: **Object is positioned at principal focus (F)**

Object MN is positioned at the principal focus (F), then ray MP parallel to the principal axis passes through principal focus (F) giving the reflected ray PS. Second ray MQ that passes through the center of curvature is reflected along the same path giving the reflected ray QR. Here, since the rays, PS and QR become parallel to each other and therefore the image formation is at infinity. Here the properties of the images formed are highly enlarged images and real and inverted images.

f. Object is positioned between principal Focus (F) and Pole (P)

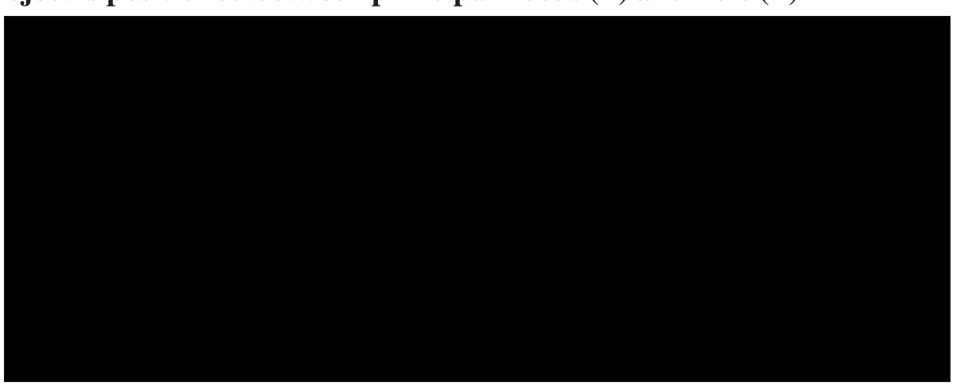


Figure 10.8: **Object is positioned between principal focus (F) and pole (P)**

Object MN is positioned between principal focus (F) and pole (P), then the ray MP parallel to principal axis passes through principal focus (F) giving the reflected ray PS and the second ray MQ that passes through the center of curvature (C) is reflected along the same path giving the reflected ray QR.

Now, since the reflected rays PR and QS are diverging away hence cannot intersect each other, hence reflected rays PS and QR are extended behind the mirror by dotted lines. In doing so, rays PR and QS appear to intersect each other at point M' backwards. Therefore, the properties of the images formed here are formed behind the mirror, images are highly enlarged, images are virtual and erect.

Table 1

Image formation by a concave mirror for different positions of the object

Position of the Object	Position of the Image	Size of the Image	Nature of the Image
At Infinity	At the focus of F	High diminished, Point-sized	Real and inverted
Beyond C	Between F and C	Diminished	Real and inverted
At C	At C	Same size	Real and inverted
Between C and F	Beyond C	Enlarged	Real and inverted
At F	At Infinity	Highly enlarged	Real and inverted
Between P and F	Behind the mirror	Enlarged	Virtual and erect

Uses of concave mirrors

Concave mirrors are commonly used in torches, search-lights and vehicles headlights to get powerful parallel beams of light. They are often used as shaving mirrors to see a larger image of the face. The dentists use concave mirrors to see large images of the teeth of patients. Large concave mirrors are used to concentrate sunlight to produce heat in solar furnaces

10.5.2 Ray Diagrams for a Convex Mirror

In case, of a convex mirror, there are only two possible positions (Fig 10.9 to 10.10) where the object can be positioned and an image can be formed.

a. Object is positioned at Infinity

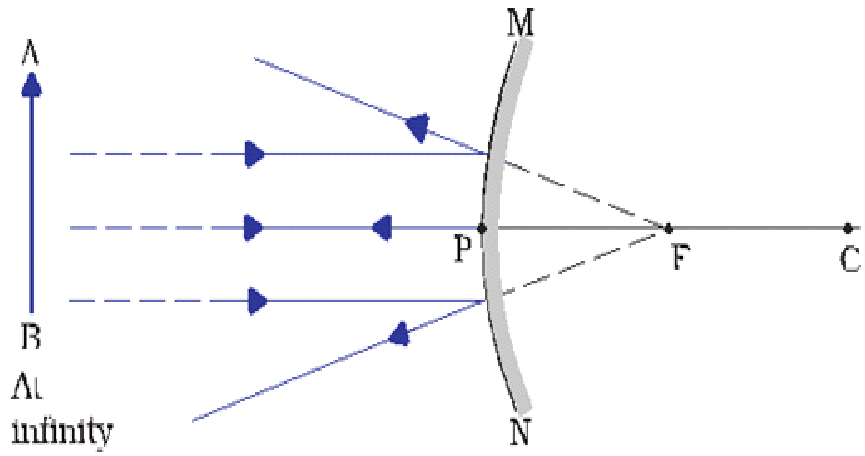


Figure 10.9: **Object is positioned at infinity**

When the object is at infinity, the rays that are parallel to the principal axis are divergent after getting reflected from the convex mirror. The diverged rays are extended behind the mirror, where they intersect each other at the principal focus (F). Hence, in this case, the properties of the images formed are formed at the principal focus (F) behind the mirror and are highly diminished, the images are virtual and erect.

b. Object is positioned between the Pole (P) and Infinity

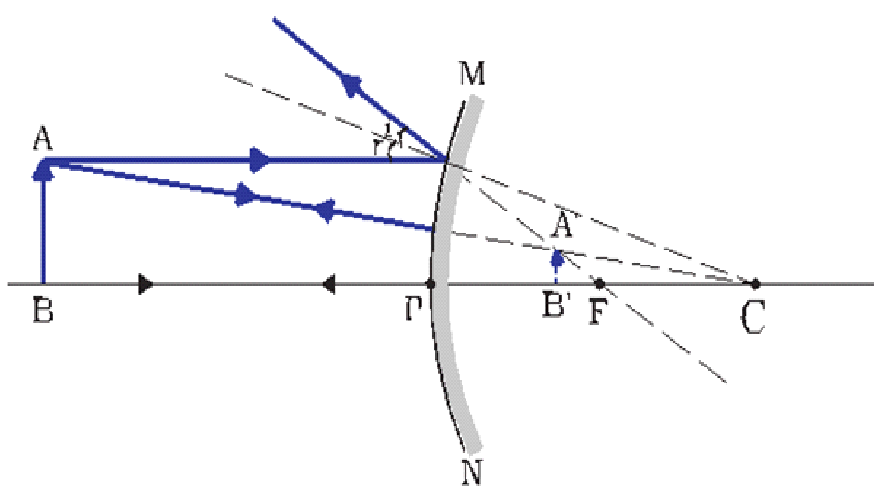


Figure 10.10: **Object is positioned between the pole (P) and infinity**

When the object AB is placed between pole (P) and infinity, a ray AYthat starts from point A of the object AB that's running parallel to the principal axis is reflected. On extending behind the mirror, FY appears to come from principal focus (F) and another ray from point A of the object AB that goes towards the center of curvature is reflected along AC. The two rays, AC and FY are diverging rays and when extended behind the mirror, they appear to intersect each other at point At.

Therefore, the properties of the images formed here are formed behind the mirror, between the pole and infinity, the images are diminished and are virtual and erect.

Table 2

Nature, position and relative size of the image formed by a convex mirror

Position of the Object	Position of the Image	Size of the Image	Nature of the Image
At Infinity	At the focus of F, behind the mirror	High diminished, Point-sized	Virtual and erect
Between infinity and the pole P of the mirror	Between P and F, behind the mirror	Diminished	Virtual and erect

Uses of convex mirrors

Convex mirrors are commonly used as rear-view (wing) mirrors in vehicles. These mirrors are fitted on the sides of the vehicle, enabling the driver to see traffic behind him/her to facilitate safe driving. Convex mirrors are preferred because they always give an erect, though diminished, image. Also, they have a wider field of view as they are curved outwards. Thus, convex mirrors enable the driver to view much larger area than would be possible with a plane mirror.

Check Your Progress-2

Note: (a) Answer the questions given below.

(b) Compare your answers with those given at the end of this lesson.

1. Fill in the blanks:

(a) If the object is placed between infinity and center of curvature (C) of a concave mirror, then the image formation is between_________________.

(b) When the object is positioned at infinity in case of convex mirror, the image formed is______________.

(c) When the object MN is placed at the center of curvature (C) of a concave mirror, the image formed is ___________.

(d) If the position of the object is at infinity, the nature of the image on case of concave is _____________.

2. State True/False:

(A) The dentists use concave mirrors to see large images of the teeth of patients. patients. ( )

(B) Concave mirrors are commonly used as rear-view mirrors in vehicles. ( )

(C) Convex mirrors are preferred to be used as rear-view mirrors because they always give an erect, though diminished, image. ( )

3. Choose the correct option for the following question:

Q. No matter how far you stand from a mirror, your image appears erect. The mirror is likely to be

(a) plane

(b) concave

(c) convex

(d) either plane or convex.

10.6 LET US SUM UP

- Light seems to travel in straight lines.
- Mirrors and lenses form images of objects. Images can be either real or virtual, depending on the position of the object.
- The reflecting surfaces, of all types, obey the laws of reflection.
- The focal length of a spherical mirror is equal to half its radius of curvature.
- Concave mirrors are commonly used in torches, search-lights and vehicles headlights to get powerful parallel beams of light.
- Convex mirrors are commonly used as rear-view (wing) mirrors in vehicles.

10.7 LESSON END EXERCISE

Q. 1. Draw neat and clean ray diagrams for concave and convex mirrors.

Q. 2. What are the uses of concave and convex mirrors?

Q. 3. What are the properties of properties of the images formed by concave and convex mirrors when object is placed at different positions?

10.8 SUGGESTED FURTHER READINGS

Reflection and Refraction (2020). Chapter 10 from NCERT Class 10th Science Book.

https://www.toppr.com/guides/physics/light-reflection-and-refraction/image-formation-by-spherical-mirrors/

https://www.learncbse.in/ncert-solutions-for-class-8-science-light/

10.9 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress-1

Q. 1.

(a) concave mirror

(b) convex mirror

(c) aperture

(d) 5 cm

Q. 2.

A. (b) pole

B. (a) midway between the pole and centre of curvature

Check Your Progress-2

Q. 1.

(a) between principal focus (F) and center of curvature (C)

(b) virtual and erect

(c) real and inverted

(d) real and inverted

Q.2.

(a) True

(b) False

(c) True

Q. 3.

(c) Conve

Lesson No. : 11 **Unit : IV**

REFRACTION

Structure

11.1 INTRODUCTION

Dear students, you might have observed while traveling on a road on a hot summer day, distantly, water appears in the middle of the road out of no-where. Also if there is only one fish in the aquarium, still it appears to be many. Do you know how this happens? This is all due to the refraction. Let us study more about refraction, laws of refraction, dispersion and scattering of light.

11.2 OBJECTIVES

After going through this lesson, you shall be able to:

- describe the concept of refraction,
- generalise the laws of refraction,
- demonstrate the concept of refractive index,
- explain refraction of light through a prism, and
- describe the concepts of dispersion and scattering of light.

11.3 REFRACTION

The change in direction or bending of a light wave passing from one transparent medium to another; caused by the change in wave's speed is known as "Refraction".

Another example of refraction is if you take a pencil/stick and dip it in water (Fig 11.1), the pencil/stick appears to be bent. It does not appear straight. Why is the pencil/stick appearing bent even though it is a straight nice pencil/stick? This is because of a phenomenon of refraction. The medium involved here is air and water. As soon as the light waves enter the water, the light rays bend and because of this bending of light waves, we see the pencil/stick as broken.

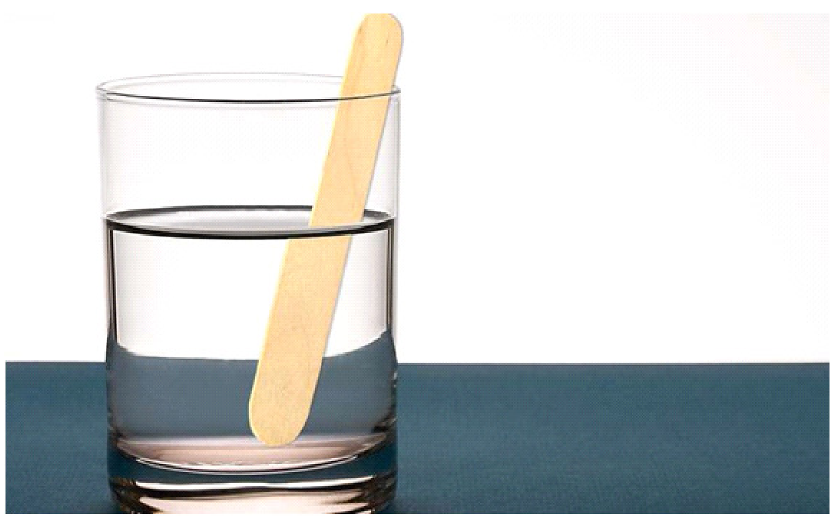


***Fig 11.1*: Straight stick appears to be bent when partly immersed in water**

Atmospheric Refraction

When the refraction of light takes place due to earth's atmosphere it is called *atmospheric refraction*. So, when light ray enter the atmosphere there is air and every air layer has different temperature. These air layers have different optical densities. Cooler air layer is an optically denser medium for light rays whereas warmer air layer is optically rarer medium for light rays.

The following are the examples of atmospheric refraction of light.

(1) Twinkling of stars

Stars twinkle at night because their light is refracted in the atmosphere. When the light of star enters the earth's atmosphere it undergoes refraction due to different optical densities of the air. Therefore, stars appear bright at one moment and dim in another.

(2) Stars appear higher than they are

The light from stars is refracted as it comes down into earth's atmosphere. The air higher up in the sky is rarer and near the earth's surface is denser. As the star light falls down the dense air bends it more and thus stars appear higher than they actually are.

(3) Advance sunrise and delayed sunset

It is due to refraction of light that we are able to see the sun two minutes before sunrise and two minutes after actual sunset. At the time of sunrise the sunlight is coming from less dense air to more dense air. In this case the sunlight is refracted downwards and because of this sun appears to be raised above the horizon than it actually is.

11.4 LAWS OF REFRACTION

The following are the laws of refraction of light:

(i) The incident ray, the refracted ray and the normal to the interface of two transparent media at the point of incidence, all lie in the same plane.

(ii) The ratio of sine of angle of incidence to the sine of angle of refraction is a constant, for the light of a given colour and for the given pair of media. This law is also known as Snell's law of refraction.

If i is the angle of incidence and r is the angle of refraction, then,

$$\frac{\sin i}{\sin r} = \text{constant}$$

The ratio of the sine of the angle of incidence and sine of the angle of refraction is constant. This constant value is called the refractive index of the second medium with respect to the first.

Check Your Progress-1

Note: (a) Answer the questions given below.

(b) Compare your answers with those given at the end of this lesson.

1. Fill in the blanks:

(a) The change in direction or bending of a light wave passing from one transparent medium to another; caused by the change in wave's speed is known as ____________.

(b) Straight stick appears to be ___________ when partly immersed in water.

(c) The incident ray, the refracted ray and the normal to the interface of two transparent media at the point of incidence, all lie in the ___________.

(d) The ratio of sine of angle of incidence to the sine of angle of refraction is a constant, for the light of a given colour and forthe given pair of media. This law is also known as ______________.

11.5 REFRACTIVE INDEX

The extent of bending of light rays entering from one medium to another is the "Refractive Index". It is denoted by the letter 'n'. It is represented as:

$$n = c/v$$

where c = velocity/speed of light of a certain wavelength in the air and v = velocity of light in any medium.

The refractive index can be linked to an important physical quantity, the relative speed of propagation of light in different media. It turns out that light propagates with different speeds in different media. Light travels the fastest in vacuum with the highest speed of 3×10^8 m s^{-1}. In air, the speed of light is only marginally less, compared to that in vacuum. It reduces considerably in glass or water. The value of the refractive index for a given pair of media depends upon the speed of light in the two media, as given below.

Consider a ray of light travelling from medium 1 into medium 2, as shown in Fig.11.2. Let v_1 be the speed of light in medium 1 and v_2 be the speed of light in medium 2. The refractive index of medium 2 with respect to medium 1 is given by the ratio of the speed of light in medium 1 and the speed of light in medium 2. This is usually represented by the symbol n_{21}. This can be expressed in an equation form as

$$n_{21} = \frac{\text{Speed of light in medium 1}}{\text{Speed of light in medium 2}} = \frac{\upsilon_1}{\upsilon_2}$$

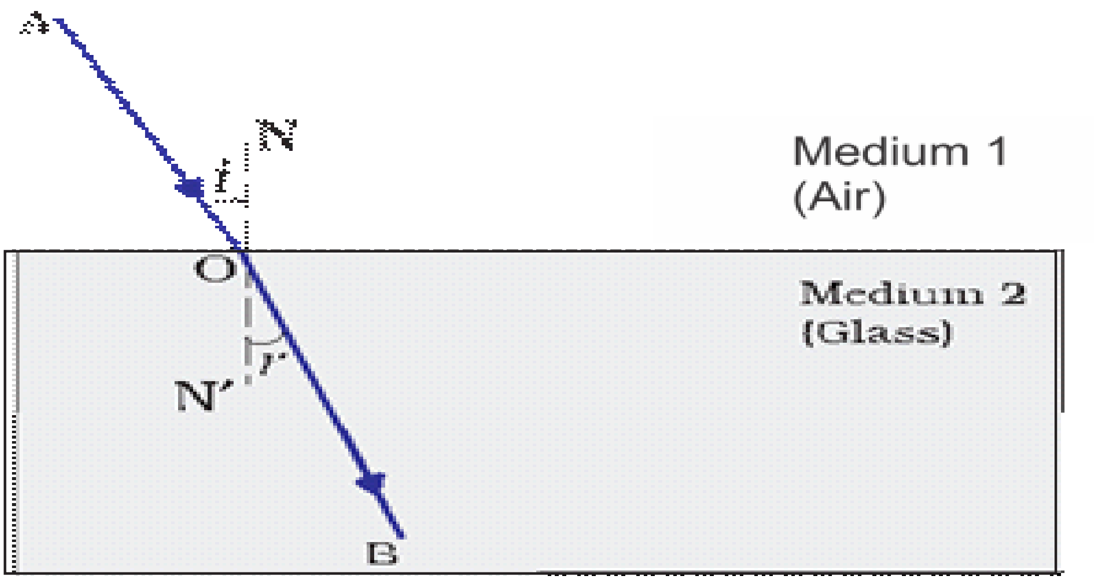


*Figure 11.2:*Refraction of light when it enters from air to glass

By the same argument, the refractive index of medium 1 with respect to medium 2 is represented as n_{12}. It is given by

$$n_{21} = \frac{\text{Speed of light in medium 2}}{\text{Speed of light in medium 1}} = \frac{\upsilon_1}{\upsilon_2}$$

If medium 1 is vacuum or air, then the refractive index of medium 2 is considered with respect to vacuum. This is called the absolute refractive index of the medium. It is simply represented as n_2. If c is the speed of light in air and v is the speed of light in the medium, then, the refractive index of the medium n_m is given by

$$n_m = \frac{\text{Speed of light in air}}{\text{Speed of light in the medium}} = \frac{c}{\upsilon}$$

The absolute refractive index of a medium is simply called its refractive index. The refractive index of several media is given in Table 11.1. From the Table you can know that the refractive index of water, $n_w = 1.33$. This means that the ratio of the speed of light in air and the speed of light in water is equal to 1.33. Similarly, the refractive index of crown glass, $n_g = 1.52$. Such data are helpful in many places.

Table 11.1 Refractive Index of Several Media

Material	Refractive Index	Material	Refractive Index
Air	1.0003	Crown glass	1.52
Ice	1.31	Canada Balsam	1.53
Water	1.33	Rock salt	1.54
Alcohol	1.36	Carbon disulphide	1.63
Kerosene	1.44	Dense flint glass	1.65
Fused quartz	1.46	Ruby	1.71
Turoentine oil	1.47	Sapphire	1.77
Benzene	1.50	Diamond	2.42

Check Your Progress-2

Note: (a) Answer the questions given below.

(b) Compare your answers with those given at the end of this lesson.

1. Fill in the blanks:

(a) The extent of bending of light rays entering from one medium to another is the _____________.

(b) Refractive Index is denoted by the letter _____________.

(c) The value of the refractive index for a given pair of media depends upon the _______________.

(d) The refractive index of medium 2 with respect to medium 1 is given by the ratio of the speed of light in __________________ and the speed of light in ________________.

(e) The refractive index of medium 2 with respect to medium 1 is represented by _____________.

2. State True/False:

(a) If medium 1 is vacuum or air, then the refractive index of medium 2 is considered with respect to vacuum. This is called the absolute refractive index of the medium. ( )

(b) The absolute refractive index of a medium is simply called its refractive index. ( )

11.6 REFRACTION OF LIGHT THROUGH A PRISM

A glass prism is a transparent object having two triangular ends and three rectangular sides. The refraction of light in glass prism is different from a glass slab. This is because in glass prism, the incident ray of light is not parallel to emergent ray of light.

When a ray of light enters the glass prism it gets deviated two times. First when it enters the glass prism and second when it comes out of the prism. This is because the refracting surfaces of the prism are not parallel to each other. Also, when the ray of light passes through the prism it bends towards its base.

- If you take a glass prism, you can see that it has 2 triangular bases and three rectangular lateral surfaces, inclined at an angle. This angle is called the angle of the prism.
- Let's look at a top view of a triangular prism with a ray of light entering it.

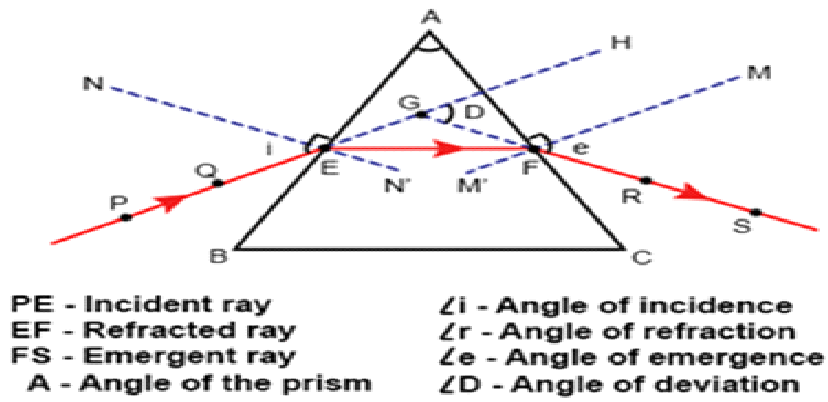


Figure 11.3: Refraction of light through prism

In the figure 11.3, A is the angle of the prism.

- As per Snell's law, light traveling from a rarer medium to a denser medium bends towards the normal, and vice versa. Glass is denser than air, and thus, when a ray of light falls on the surface of the prism, it bends towards the normal. According to the diagram, ray PE falls on the surface of the prism and bends towards the normal NE.
- Then, while moving from the glass to air, the emergent ray FS bends away from the normal.
- "HDS is the angle of deviation which tells us how much the emergent ray has deviated from the incident ray. When the angle of incidence is equal to the angle of emergence, the angle of deviation is minimum.
- According to the figure, "PEN" = "MES" and "HDS" is thus the angle of minimum deviation. The refracted ray EF is parallel to side BC in this case.

This is how a ray of white light scatters into seven colours when it passes through a prism. The different colors of light wave experience a different degree of deviation and thus white light splits into its components when it is subjected to refraction.

11.7 DISPERSION AND SCATTERING OF LIGHT

Dispersion of light

In 1665, Isaac Newton discovered that white light consists of seven colours.

He found that if a beam of white light is passed through glass prism then it will split in to seven colours. These colours are violet, indigo, blue, green, yellow, orange and red (VIBGYOR).The band of seven colours formed when a beam of white light is passes through a glass prism is called spectrum of white light. The splitting of white light into seven colours on passing through a transparent medium is called dispersion of light.

The dispersion of white light happens because the angle of refraction of lights of different colours is different while passing through the transparent medium. For example, red colour deviates least and is formed at the upper part of the spectrum and violet colour is deviated maximum and is formed at the bottom of the spectrum (Figure 11.4).

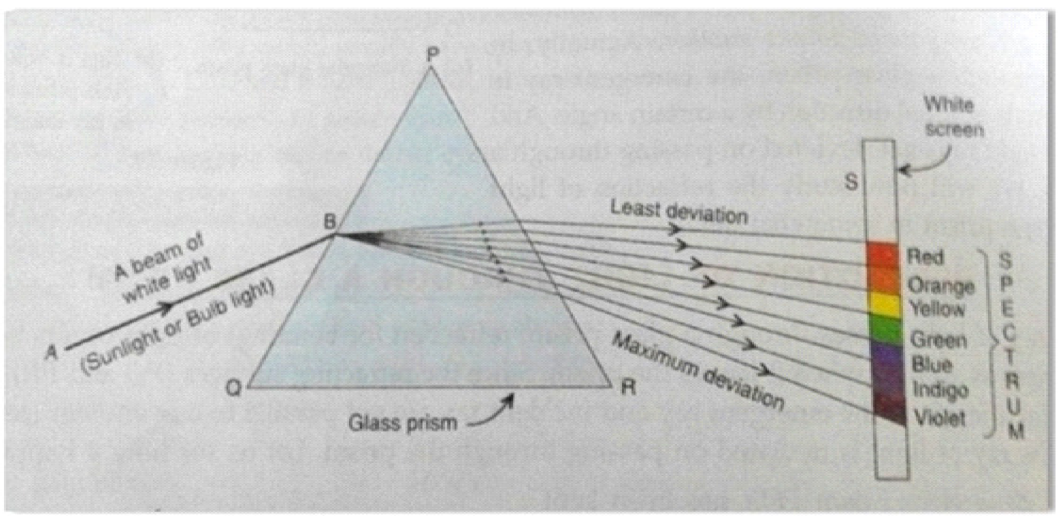


Figure 11.4: Dispersion of light

It is the phenomenon in which white light splits into its constituent colours. White light contains several constituents that vary in their wavelengths (it contains the light of different colours). Since the wavelengths of these constituents are different, their speeds differ from each other in a medium. Note that their speed in a vacuum is the same. In a material medium, the speed of different wavelengths is different.

Rainbow is formed when it is raining at the time of sunshine. When the white sunlight falls on the raindrops and leaves them, then the white light is refracted and an arc of seven colours is formed in the sky. In this situation, tiny raindrops act as glass prism splitting the white sunlight.

Scattering of Light

Scattering of light can be defined as the deviation of light rays from their straight trajectory. As light propagates through the atmosphere, it travels in a straight path until comes under obstruction from the gas molecules and dust particles in the atmosphere. The process in which light gets deflected by the tiny particles in the medium through which the light passes is called scattering.

Here the light is not split into its constituent colours. Rather, the incident beam of light just gets redirected after being struck by the atmospheric particles. The blue colour of the sky is due to the scattering of sunlight by the molecules of air. During sunset, sunlight has to travel a greater distance, so shorter wavelengths get scattered off and removed and only red wavelengths reach us.

When light is scattered due to particles in its path, it is called Tyndall effect. The way a beam of sunlight becomes visible when it passes through dust particles in a room, when sunlight passes through a canopy of dense forest etc., are examples of Tyndall effect.

In 1859, Tyndall discovered that when white light is passed through clear liquid having small suspended particles, then the blue colour of white light has shorter wavelength and is scattered more than the red colour that has longer wavelength.

- The colour of scattered light depends on the size of particles
- It is due to the scattered large dust particles and water droplets in the atmosphere that when white sunlight falls on them it is reflected in such a way that the scattered light also appears white. Dust particles and water droplets in the atmosphere are larger than the wavelength range of the visible light.
- The extremely small air molecules in the atmosphere scatter mainly blue light when white sunlight falls on them. This is because blue colour has lower wavelength and is much more by the air molecules.

Why the sky is blue?

When white sunlight falls in the atmosphere, lights with longer wavelength are not scattered by the air molecules. It is only the blue light which has shorter wavelength that is scattered most by the air molecules in the atmosphere. This is why the sky looks blue.

Why the Sun appears red at sunrise and sunset?

At the time of sun rise and sunset all the blue coloured light is scattered out and is away from our sight. So the light reaching us mainly at the time of sunrise and sunset is red which has longer wavelength.

Check Your Progress-3

Note: (a) Answer the questions given below.

(b) Compare your answers with those given at the end of this lesson.

1. Fill in the blanks:

(a) A glass prism is a transparent object having __________ triangular ends and __________ rectangular sides.

(b) ___________ is the phenomenon in which white light splits into its constituent colours.

(c) Dispersion of light in a prism results in the formation of a ___________.

(d) When light is scattered due to particles in its path, it is called __________.

11.8 LET US SUM UP

- The refracting surfaces obey the laws of refraction.
- A light ray travelling obliquely from a denser medium to a rarer medium bends away from the normal. A light ray bends towards the normal when it travels obliquely from a rarer to a denser medium.
- Light travels in vacuum with an enormous speed of 3×10^8 m s^{-1}. The speed of light is different in different media.
- The refractive index of a transparent medium is the ratio of the speed of light in vacuum to that in the medium.

- In case of a rectangular glass slab, the refraction takes place at both air-glass interface and glass-air interface. The emergent ray is parallel to the direction of incident ray.
- Refraction is the cause for a lot more phenomena.
- When you look at a straw dipped in a glass of water, the part in the air and the part in water look like they are not the same straw! It looks distorted.
- Sometimes, in a desert, travelers see water or trees on the ground, when there is actually nothing there. This phenomena is known as 'mirage'.
- Some other natural phenomena that also occur because of refraction, such as the twinkling of stars and the formation of rainbows.
- When a beam of white light passes through a medium, the material medium splits the white light into different components. This phenomenon is called dispersion. When white light passes through a prism, it disperses into a band of seven different colours. This band of colours obtained from the dispersion of light is called a spectrum.

11.9 LESSON END EXERCISE

Q. 1. Explain the concept of refraction and refractive index.

Q.2. Draw a well labelled diagram showing refraction of light through prism.

Q. 3. What do you mean by dispersion?

Q. 4. Write a note on scattering of light.

11.10 SUGGESTED FURTHER READINGS

Dispersion (2020). https://www.britannica.com/science/dispersion-physics

Refraction (2020). https://www.toppr.com/content/concept/laws-of-refraction-210214/

Reflection and Refraction (2019). Chapter 10 from NCERT Class 10^{th} Science Book.

Refraction of Light through a Glass Prism. https://byjus.com/physics/refraction-light-glass-prism/

11.11 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress-1

Q. 1.

a. Refraction

b. Bent

c. same plane

d. Snell's law of refraction

Check Your Progress-2

Q. 1.

a. Refractive Index

b. n

c. speed of light in the two media

d. medium 1, medium 2

e. n_{21}

Q. 2.

a. True

b. True

Check Your Progress-3

a. two, three

b. Dispersion

c. Spectrum

d. Tyndall effect

Lesson No. : 12 **Unit : IV**

METALS AND NON - METALS

Structure

12.1 INTRODUCTION

Dear students, the materials present around us are grouped widely into metals and non-metals. So, it is important to know whether a particular element is a metal or non-metal. This lesson shall cover the properties of metals and non-metals and enable you to differentiate between metals and non-metals. The concept and prevention of corrosion have also been discussed.

12.2 OBJECTIVES

After going through this lesson, you shall be able to:

- explain the physical and chemical properties of metals,
- describe the physical and chemical properties of non-metals,
- differentiate between metals and non-metals, and
- explain the concept and prevention of corrosion.

12.3 METALS

Metals, as chemical elements, comprise 25% of earth's crust and are present in many aspects of modern life. The history of refined metals is thought to begin with the use of copper about 11,000 years ago. Gold, silver, iron, lead, and brass were likewise in use before the first known appearance of bronze in the 5th millennium BCE.

12.3.1 Physical Properties

The physical properties of metals are:

Luster

The metals in their pure state usually shine. This property of metals is called luster. The shine on the metallic surface is the metallic luster. They shine in light due to the reason that the metals possess free electrons that vibrate on getting in contact with light.

Malleability

Malleability refers to the property of metals by which they can be beaten into thin sheets. Gold and silver are the most malleable metals. One such example is silver foil made from beaten silver metal for decorating sweets.

Ductility

The ability of metals to be drawn into thin wires is called ductility. Gold is the most ductile metal. You will be surprised to know that a wire of about 2 km length can be drawn from one gram of gold.

Conductivity

The metals are a good conductor of heat and electricity as they can pass through them. They are good conductors of heat and electricity. The best conductors of electricity are silver and copper, however, lead and mercury are poor conductors of electricity.

High melting point

Metals have high melting point except Caesium and Galium have the very low melting point.

Sonorous

On being struck hard, the metals produce a ringing sound. Due to this property, they sonorous. For example- the school bell produces a loud ringing sound when struck with hammer hard. Some examples are- Iron, Gold, Copper, Aluminium, Magnesium, and many more.

Solid

Except for mercury, all the metals are solid. Mercury is in the liquid state at room temperature. The exceptional metals are Sodium (Na), Potassium (K) and Mercury (Hg). The metals like Sodium (Na) and Potassium(K) are easily cut with the help of a knife. Other examples of metals are iron, copper, silver, aluminium, calcium, gold etc.

12.3.2 Chemical Properties

The chemical properties of metal are:

Reaction with Oxygen (Oxidation)

All metals except the noble metals, which is gold and silver react with the oxygen to form basic oxides. In the reaction, the metal reacts vigorously with oxygen and generates a lot of heat. The reaction has been given below:

Magnesium (Mg) + Oxygen (O_2) $\longrightarrow$ 2MgO (Magnesium Oxide)

Rusting of Iron

Iron (Fe) + Oxygen (O_2) + Water (H_2O) $\longrightarrow$ Fe_2O_3(Iron Oxide, is brown colour rust)

Greenish Deposit on the Surface of Copper Vessels

The dull greenish material that is deposited on the surface of copper is a mixture of copper hydro oxide [$Cu(OH)_2$] and copper carbonate ($CuCO_3$) which takes place as –

$$2Cu + H_2O + CO_2 + O_2 \longrightarrow [Cu(OH)_2] + (CuCO_3)$$

We have learnt that metal oxides are basic in nature (turn red litmus blue). But some metal oxides, such as aluminium oxide, zinc oxide, etc., show both acidic as well as basic behaviour. Such metal oxides which react with both acids as well as bases to produce salts and water are known as amphoteric oxides. Aluminium oxide reacts in the following manner with acids and bases –

$$Al_2O_3 + 6HCl \longrightarrow 2AlCl_3 + 3H_2O$$

$$Al_2O_3 + 2NaOH \longrightarrow \underset{\text{(Sodium aluminate)}}{2NaAlO_2} + H_2O$$

Most metal oxides are insoluble in water but some of these dissolve in water to form alkalis. Sodium oxide and potassium oxide dissolve in water to produce alkalis as follows –

$$Na_2O(s) + H_2O(l) \longrightarrow 2NaOH(aq)$$

$$K_2O(s) + H_2O(l) \longrightarrow 2KOH(aq)$$

All metals do not react with oxygen at the same rate. Different metals show different reactivities towards oxygen. Metals such as potassium and sodium react so vigorously that they catch fire if kept in the open. Hence, to protect them and to prevent accidental fires, they are kept immersed in kerosene oil. At ordinary temperature, the surfaces of metals such as magnesium, aluminium, zinc, lead, etc., are covered with a thin layer of oxide. The protective oxide layer prevents the metal from further oxidation. Iron does not burn on heating but iron filings burn vigorously when sprinkled in the flame of the burner. Copper does not burn, but the hot metal is coated with a black coloured layer of copper(II) oxide. Silver and gold do not react with oxygen even at high temperatures.

Reaction with Water (Hydrolysis)

Metals react with water and produce a metal oxide and hydrogen gas. Metal oxides that are soluble in water dissolve in it to further form metal hydroxide. But all metals do not react with water.

Metal + Water $\longrightarrow$ Metal oxide + Hydrogen

Metal oxide + Water $\longrightarrow$ Metal hydroxide

Metals like potassium and sodium react violently with cold water. In case of sodium and potassium, the reaction is so violent and exothermic that the evolved hydrogen immediately catches fire.

$2K(s) + 2H_2O(l) \longrightarrow 2KOH(aq) + H_2(g) + \text{heat energy}$

$2Na(s) + 2H_2O(l) \longrightarrow 2NaOH(aq) + H_2(g) + \text{heat energy}$

The reaction of calcium with water is less violent. The heat evolved is not sufficient for the hydrogen to catch fire.

$Ca(s) + 2H_2O(l) \longrightarrow Ca(OH)_2(aq) + H_2(g)$

Calcium starts floating because the bubbles of hydrogen gas formed stick to the surface of the metal.

Magnesium does not react with cold water. It reacts with hot water to form magnesium hydroxide and hydrogen. It also starts floating due to the bubbles of hydrogen gas sticking to its surface.

Metals like aluminium, iron and zinc do not react either with cold or hot water. But they react with steam to form the metal oxide and hydrogen.

$2Al(s) + 3H_2O(g) \longrightarrow Al_2O_3(s) + 3H_2(g)$

$3Fe(s) + 4H_2O(g) \longrightarrow Fe_3O_4(s) + 4H_2(g)$

Metals such as lead, copper, silver and gold do not react with water at all.

Reaction with Acids (Acidity)

Metals react with acids to give a salt and hydrogen gas (burns with a ‘pop’ sound).

Metal + Dilute acid $\longrightarrow$ Salt + Hydrogen

Zinc + Hydrochloric acid $\longrightarrow$ Zinc chloride + Hydrogen

$Zn + 2HCl \longrightarrow ZnCl_2 + H_2$

$Zn + H_2SO_4 \longrightarrow ZnSO_4 + H_2$

Hydrogen gas is not evolved when a metal reacts with nitric acid. It is because HNO_3 is a strong oxidising agent. It oxidises the H_2 produced to water and itself gets reduced to any of the nitrogen oxides (N_2O, NO, NO_2). But magnesium (Mg) and manganese (Mn) react with very dilute HNO_3 to evolve H_2 gas.

Aqua regia, (Latin for ‘royal water’) is a freshly prepared mixture of concentrated hydrochloric acid and concentrated nitric acid in the ratio of 3:1. It can dissolve gold, even though neither of these acids can do so alone. Aqua regia is a highly corrosive, fuming liquid. It is one of the few reagents that is able to dissolve gold and platinum.

Reaction with Solutions of other Metal Salts

Reactive metals can displace less reactive metals from their compounds in solution or molten form.

As we know that all metals are not equally reactive. If metal A displaces metal B from its solution, it is more reactive than B.

Metal A + Salt solution of B $\longrightarrow$ Salt solution of A + Metal B

In the reaction between copper sulphate ($CuSO_4$) and zinc (Zn), zinc (Zn) replaces copper (Cu) from copper sulphate (CuSO4). That is why the blue colour of copper sulphate disappears and a powdery red mass of copper is deposited at the bottom of the beaker. The reaction can be represented as follows:

Copper Sulphate ($CuSO_4$) + Zinc (Zn) $\longrightarrow$ Zinc Sulphate ($ZnSO_4$) + Copper (Cu)

(Blue) (Colourless) (Red)

But here is another reaction:

Zinc Sulphate ($ZnSO_4$) + Copper turnings (Cu) $\longrightarrow$ No displacement.

In this reaction, copper is less reactive than zinc, so it cannot replace zinc from its salt zinc sulphate. A more reactive metal can replace a less reactive metal, but a less reactive one cannot replace a more reactive metal.

The Reactivity Series

The reactivity series is a list of metals arranged in the order of their decreasing activities. After performing displacement experiments, the following series, known as the reactivity or activity series has been developed.

K > N a > C a > Mg > Al > Zn > Fe > Pb > H > Cu > Hg > Ag > Au

Most reactive $\longrightarrow$ Least reactive

Reactivity Decreases

Uses of Metals

- Metals are used to make tools because they can be strong and easy to shape. Iron and steel have been used to make bridges, buildings, or ships.
- Some metals are used to make items like coins because they are hard and will not wear away quickly. Some metals, like steel, can be made sharp and stay sharp, so they can be used to make knives, axes or razors.
- Rare metals with high value, like gold, silver and platinum are often used to make jewellery. Metals are also used to make fasteners and screws.
- Pots used for cooking can be made from copper, aluminium, steel or iron.
- Lead is very heavy and dense and can be used as ballast in boats to stop them from turning over, or to protect people from ionizing radiation.

Check Your Progress-1

Note: (a) Answer the questions given below.

(b) Compare your answers with those given at the end of this lesson.

1. Which of the following can be beaten into thin sheets?

   (A) Zinc (b) Phosphorus (c) Sulphur (d) Oxygen

2. Which of the following statements is correct?

   (a) Sodium is a very reactive metal. ( )

   (b) Copper displaces zinc from zinc sulphate solution. ( )

   (c) Generally, metals are not ductile. ( )

   (d) Metals are not malleable. ( )

3. Fill in the blanks.

   (a) Metals are conductors of heat and ___________.

   (b) Iron is __________ reactive than copper.

   (c) Metals react with acids to produce ___________ gas.

12.4 NON-METALS

Non-metals are materials not holding the characteristics of metals, means they are not shiny, hard, fusible, malleable, ductile, etc. Many materials like coal and sulphur are very soft and dull in appearance. They break down into very fine thin powdery mass on tapping with the hammer. They are neither in – sonorous and also are a very poor conductor of heat and electricity. In the periodic table non-metals are kept almost in the right most. In modern periodic table there are 22 non-metals in which there are 11 gases, 1 liquid and 10 solid. Bromine occurs in the state of liquid and hydrogen, nitrogen, oxygen, chlorine etc are found in gaseous forms. But carbon, sulphur, phosphorous, iodine etc solid non-metals.

12.4.1 Physical Properties

The physical properties of non-metals are:

The solid non-metals are brittle or dull and soft as they can be broken down into a powdery substance or mass on tapping down with the hammer. Few examples are Coal and Sulphur. However, Diamond is an exception as it is the hardest non-metal.

- Non – metals may be either solids, liquids, or gases.
- Non-metals are poor conductors of heat and electricity except Graphite.
- They do not possess metallic luster.
- Non-metals are not sonorous, they do not produce a ringing sound.
- Non-metals possess no malleability.
- They are not ductile.
- They have dull luster, however, iodine is lustrous.

Some example of non – metals are carbon, oxygen, sulphur, phosphorous, and many more.

12.4.2 Chemical Properties of Non-Metals

Reaction with Oxygen (Oxidation)

Generally, oxides of non-metals are acidic in nature.

Sulphur dioxide gasis formed in the reaction of sulphur and oxygen. When sulphur dioxide is dissolved in water sulphurous acid is formed. The reaction can be given as follows: Sulphur dioxide (SO_2) + Water (H_2O) ’! Sulphurous acid (H_2SO_3) The sulphurous acid turns blue litmus paper red.

Reaction with Water (Hydrolysis)

Most non-metals produce acidic oxides when dissolved in water. Other non-metals do not react with water though they may be very reactive in air. Such non-metals are stored in water. For example, phosphorus is a very reactive non-metal. It catches fire if exposed to air. To prevent the contact of phosphorus with atmospheric oxygen, it is stored in water.

Reaction with Acids (Acidity)

Non-metals generally do not react with acids.

Reaction with Bases

Non-metals generally do not react with bases.

Uses of Non Metals

- Many non-metals like chlorine, sulphur, iodine are very useful for medicinal purposes.
- Non-metal like oxygen is very essential for our life for respiration.
- We use nitrogen phosphorus in fertilizers for better plant growth and enhance the fertility of the soil.
- Non-metal like sulphur is used in crackers.
- Chlorine and fluorine are useful for the water purification purpose.

Check Your Progress-2

Note: (a) Answer the questions given below.

(b) Compare your answers with those given at the end of this lesson.

1. Most non-metals produce _________ oxides when dissolved in water.

   (a) Basic

   (b) Acidic

   (c) Neutral Compounds

   (d) None of the above.

2. Mark 'T' if the statement is true and 'F' if it is false:

   (a) Generally, non-metals react with acids. ( )

   (b) All non-metals are ductile. ( )

   (c) Phosphorus is a very reactive non-metal. ( )

   (d) Coal can be drawn into wires. ( )

12.5 DIFFERENCE BETWEEN METALS AND NON-METALS

Metals	Non-Metals
1. Metals are lustrous.	1. Non-metals have no lustre. Exception: Iodine is a non-metal but it is lustrous.
2. Generally, metals are malleable and ductile.	2. Non-metals are not malleable and ductile.
3. Generally, metals are good conductors of heat and electricity.	3. Non-metals are poor conductors of heat and electricity. Exception: Graphite, an allotrope of carbon, is a conductor of electricity.
4. On burning, metals react with oxygen to produce metal oxides which are basic in nature.	4. Non-metals react with oxygen to produce non- metallic oxides which are acidic in nature.
5. Some metals react with water to produce metal hydroxides and hydrogen gas.	5. Generally, non-metals do not react with water.
6. Metals react with acids and produce metal salts and hydrogen gas.	6. Generally, oxides of non-metals are acidic in nature.
7. Some metals react with bases to produce hydrogen gas.	7. Non-metals generally do not react with bases.
8. Metals have high melting points but gallium and caesium have very low melting points.	8. Non-metals tend to have comparatively low boiling and melting points. Exception: Diamond, an allotrope of carbon, has a very high melting and boiling point.
9. All metals except mercury exist as solids at room temperature.	9. The non-metals are either solids or gases except bromine which is a liquid.
10. Metals are generally hard. Exception: Alkali metals (lithium, sodium, potassium) are so soft that they can be cut with a knife.	10. Diamond, an allotrope of carbon, is the hardest natural substance known.

12.6 CORROSION AND ITS PREVENTION

Corrosion is a process where the metal corrodes. When a metal is attacked by substances around it such as moisture, acids, etc., it is said to corrode and this process is called corrosion. It is a process where the water or the moisture on the surface of the metal oxidizes with the atmospheric oxygen, it is an oxidation reaction. The black coating on silver and the green coating on copper are other examples of corrosion. Corrosion causes damage to construction, bridges, car bodies, bridges, iron railings, ships and to all objects made of metals, especially those of iron. Corrosion of iron is a serious problem. Every year an enormous amount of money is spent to replace damaged iron. Aluminum is also an important structural metal, but even aluminum goes under oxidation reactions. However, aluminum doesn't corrode or oxidize as rapidly as its reactivity suggests. An alloy of aluminum or any other metal like magnesium can make aluminum stronger, stiffer and harder.

The alkali metals like sodium need to be stored in oil as they corrode quickly. Less reactive metals like lead and copper are used to roof situations. Copper (Cu) corrodes and forms a basic green carbonate and lead corrodes to form a white lead oxide or carbonate.

Silver articles become black after some time when exposed to air. This is because it reacts with sulphur in the air to form a coating of silver sulphide.

Copper reacts with moist carbon dioxide in the air and slowly loses its shiny brown surface and gains a green coat. This green substance is copper carbonate.

Iron when exposed to moist air for a long time acquires a coating of a brown flaky substance called rust.

The iron pillar near the Qutub Minar in Delhi did not get rust though it was built more than 1600 years ago by the iron workers of India. They had developed a process which prevented iron from rusting.

Prevention of Corrosion

Covering the surface of the metal with enamel and lacquers helps to protect the metal against corrosion, parts of machines that move can be protected by coating layers of water repellent oil or grease. Another way of protecting iron and steel is by painting on them as it creates a barrier between the surface of the metal and moist air or water. Whereas, the other methods of protecting a metal are alloying, galvanizing, electroplating, etc.

Alloying

An alloy is a mixture of two or more metals. Alloying is a process where metals like iron or steel are mixed with a less reactive metal like chromium, magnesium, etc for protection against corrosion and to create non-rusting alloys. For e.g. Brass is an alloy which consists of copper is a cheap and non – reactive alloy. Another example of a non-rusting alloy is stainless steel, a mixture of iron and carbon.

Galvanizing

Coating iron or steel with Zinc to prevent corrosion is known as galvanizing. Dipping iron or steel in a liquid form of zinc and using it as the negative cathode zinc is coated on it, the layer is produced by electrolytic deposition. Zinc oxides or corrodes to create a zinc oxide layer that does not flake off like iron oxide rust.

Electroplating

Electroplating is a process where a metal is coated by electrolytic deposition with chromium, silver, or another metal. This process is generally held at room temperature from aqueous electrolytes. It is one of the most popular and common methods to prevent corrosion.

Check Your Progress-3

Note: (a) Answer the questions given below.

(b) Compare your answers with those given at the end of this lesson.

1. The surface of some metals, such as iron, is corroded when they are exposed to _____ for a long period of time.

   (a) moist air

   (b) oil

   (c) grease

   (d) paint

2. Which of the following metals corrodes quickly?

(a) Gold (Au)

(b) Silver (Ag)

(c) Copper (Cu)

(d) Iron (Fe)

3. Which of the following methods is suitable for preventing an iron frying pan from rusting?

(a) Applying grease

(b) Applying paint(

(c) Applying a coating of zinc

(d) All of the above.

12.7 LET US SUM UP

- Elements can be classified as metals and non-metals.
- Metals are lustrous, malleable, ductile and are good conductors of heat and electricity. They are solids at room temperature, except mercury which is a liquid.
- Metals combine with oxygen to form basic oxides. Aluminium oxide and zinc oxide show the properties of both basic as well as acidic oxides. These oxides are known as amphoteric oxides.
- Different metals have different reactivities with water and dilute acids.
- A list of common metals arranged in order of their decreasing reactivity is known as an activity series.
- Metals above hydrogen in the Activity series can displace hydrogen from dilute acids.
- A more reactive metal displaces a less reactive metal from its salt solution.
- Non-metals have properties opposite to that of metals. They are neither

malleable nor ductile. They are bad conductors of heat and electricity, except for graphite, which conducts electricity.

- The surface of some metals, such as iron, is corroded when they are exposed to moist air for a long period of time. This phenomenon is known as corrosion.

2.8 LESSON END EXERCISE

1. Between two metals tin and zinc which metal will be preferred for coating food cans?
2. How can you distinguish between samples of metals and non-metals?
3. What are amphoteric oxides? Give one example of amphoteric oxide.
4. What is corrosion? How can it be prevented?

12.9 SUGGESTED FURTHER READINGS

Corrosion Prevention Methods. https://eoncoat.com/corrosion-prevention-methods/

Metals and Non-metals (2020). Chapter 3 from NCERT Class 10^{th} Science Book.

Metals and Non-metals (2020). YouTube link https://youtu.be/AJbe5THaNuU

Metals versus Non-metals. https://www.thoughtco.com/metals-versus-nonmetals-608809

12.10 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress-1

1. (a) zinc
2. (a) Sodium is a very reactive metal.
3. (a) electricity

   (b) more

   (c) hydrogen

Check Your Progress-2

1. (b) Acidic

2. (a) F

(b) F

(c) T

(d) F

Check Your Progress-3

1. (a) moist air
2. (d) Iron (Fe)
3. (d) All of the above