ગુજરાત રાજ્યના શિક્ષણવિભાગના પત્ર-ક્રમાંક
મશબ / 1211 / 415 / છ, તા. 12-1-2012– થી મંજૂર

SCIENCE AND TECHNOLOGY

Standard 10

PLEDGE

India is my country.
All Indians are my brothers and sisters.
I love my country and I am proud of its rich and varied heritage.
I shall always strive to be worthy of it.
I shall respect my parents, teachers and all my elders and treat everyone with courtesy.
I pledge my devotion to my country and its people.
My happiness lies in their well-being and prosperity.

રાજ્ય સરકારની વિનામૂલ્યે યોજના હેઠળનું પુસ્તક

Gujarat State Board of School Textbooks
'Vidyayan', Sector 10-A, Gandhinagar-382010

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PREFACE

The Gujarat State Secondary and Higher Secondary Education Board has prepared new syllabi in accordance with the new national syllabi prepared by the NCERT based on NCF-2005 and core-curriculum. These syllabi are sanctioned by the Government of Gujarat.

It is a pleasure for the Gujarat State Board of School Textbooks to place before the students this textbook of **Science and Technology, Standard 10** prepared according to the new syllabus.

Before publishing the textbook, its manuscript has been fully reviewed by experts and teachers teaching at this level. Following suggestions given by teachers and experts. We have made necessary changes in the manuscript before publishing the textbook.

The Board has taken special care to ensure that this textbook is interesting, useful and free from errors. However, we welcome any suggestion, from people interested in education, to improve the quality of the textbook.

Dr. Bharat Pandit
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Date : 3-3-2015

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First Edition : 2012, Reprint : 2012, 2013, 2014

Published by : Bharat Pandit, Director, on behalf of Gujarat State Board of School Textbooks, 'Vidyayan', Sector 10-A, Gandhinagar

Printed by :

FUNDAMENTAL DUTIES

It shall be the duty of every citizen of India

(A) to abide by the Constitution and respect its ideals and institutions, the National Flag and the National Anthem;

(B) to cherish and follow the noble ideals which inspired our national struggle for freedom;

(C) to uphold and protect the sovereignty, unity and integrity of India;

(D) to defend the country and render national service when called upon to do so;

(E) to promote harmony and the spirit of common brotherhood amongst all the people of India transcending religious, linguistic and regional or sectional diversities; to renounce practices derogatory to the dignity of women;

(F) to value and preserve the rich heritage of our composite culture;

(G) to protect and improve the natural environment including forests, lakes, rivers and wild life, and to have compassion for living creatures;

(H) to develop the scientific temper, humanism and the spirit of inquiry and reform;

(I) to safeguard public property and to abjure violence;

(J) to strive towards excellence in all spheres of individual and collective activity so that the nation constantly rises to higher levels of endeavour and achievement;

(K) to provide opportunities for education by the parent or the guardian, to his child or a ward between the age of 6-14 years as the case may be.

* Constitution of India : Section 51-A

INDEX

UNIT

1

AN INTRODUCTION TO NANOTECHNOLOGY

1.1 Introduction

The word 'Nanotechnology' comprises of two words : Nano and Technology. 'Nano' is a Greek word meaning dwarf or small. In mathematical notation, nanometer means one billionth of a meter, i.e.

$$1 \text{ nanometer (nm)} = \frac{1}{1,000,000,000} = 10^{-9} \text{ meter (m)}$$

In the present context 'technology' means the technique to convert scientific principles to design or synthesis new materials, devices for prosperity, comforts and betterment of human life. It is in turn also useful to explore and understand the basic ideas underlying any scientific happenings.

The fantasy of the 'nano-world' is realised as many materials when reduced below 100 nm in size they show markedly different properties compared to their bulk properties. For example, improved mechanical strength, higher thermal and electrical conductivity, different optical properties, etc. These features are always invitable for future technological and engineering developments. In the words of Nobel Laureate Physicist of California Institute of Technology, Prof. Richard P. Feynman (1959). "There is Plenty of Room at the Bottom." He emphasised on the concept of "miniaturisation" in order to improve the functional efficiency of the material or device. However, it was much later in 1980s, K. Eric Drexler first coined the word 'Nanotechnology.'

For Information Only

Richard P. Feynman

Birth	:	May 11, 1918. Far Rockaway, Queens, New York, U.S.
Death	:	February 15, 1988. Los Angeles, California, U.S.
Nationality	:	American
Research Field	:	Theoretical Physics
Alma Mater	:	B.S. (Massachusetts Institute of Technology) Ph.D. (Prineceton University)
Awards	:	Albert Einstein Award (1954), E.O. Lawrence Award (1962), Nobel Prize in Physics (1965), Oersted Medal (1972), National Medal of Science (1979)

1.2 Nanotechnology and Nanoscience

We may now ask " What actually a nanotechnology is ? " According to CRN's (Center for Responsible Nanotechnology) definition, it is the engineering of tailoring of functional systems at the molecular or atomic scale. Before we go into details of nanotechnology, let us define what is nanoscience.

Nanoscience involves the understanding of matter whose at least one of the dimensions is 1 nm – 100 nm or less then it. It is the study of fundamental principles that the nature permits at the nanoscale or less than that i.e. the 'Quantum Mechanics.'

For Information Only

At nanoscale, laws of Newtonian mechanics fail and we require to invoke Quantum mechanics (which you will learn in higher studies) to understand interactions/forces prevailing among atoms and molecules.

On the otherhand, nanotechnology uses the understanding gained through the nanoscience to fabricate or synthesis improved materials and devices. Prof. Feynman described such atomic scale fabrication as a **'bottom-up'** approach, as opposed to conventional **'top-down'** technological approach.

For Information Only

"The principles of physics as far as I can see, do not speak against the possibility of maneuvering things atom-by-atom. It is not an attempt to violate any laws, it is something, in principle, that can be done, but in practice, it has not been done because we are too big." **- R. P. Feynman, 29th December, 1959**

In bottom-up manufacturing of devices, positionally - controlled atom-by-atom or molecule by - molecule nanostructures or nanoparticles are designed to achieve desired properties. In nanotechnology, a 'particle' is defined as a small object which behaves as a whole unit in terms of its transport and other properties. With this view, **'nanoparticles'** are sized 1 – 100 nm. Even if the size of most molecules would fit into this limit, individual molecules are generally not considered as nanoparticles.

Although, nanotechnology is considered as an invention of modern science, its use has been identified from long past. For example, nanoparticles were used by artisans as far back as the 9th century for generating a glittering effect on the surface of pots. A hair-dye formula used 2000 years ago by Greeks and Romans, works by causing tiny nanoparticles. Ancient Egyptians were using nano-lead compound for eye-make up. The Damascus steel with carbon nanoparticles on the surface was found on the surface of the sword of Tipu Sultan (Figure 1.1). 'Bhasmas' an ayurvedic medicines - are actually metallic mineral preparations of biologically produced nanoparticles. And history is long - it is Michael Faraday (1857) who gave first scientific description about how materials show drastically different and unique properties at the nano-scale.

As the invention of electricity and transistor gave new technological path ways, nanotechnology too will enable us to allow radical new things in virtually every technological and scientific arena;

whether it is communication or transportation, agriculture or industry, engineering or military affairs (weapons, etc.), medicines or cosmetics, space engineering or domestic purposes, economics or environmental issues, clean and abundant energy problems or whatever you name it. Thus, nanotechnology seems to be the general purpose technology. Higher efficiency meaning higher performances that is the reason to call it correctly the 'Green technology.'

Scientists and technocrets expect fully matured nanotechnology to be functioning by the year 2025.

Dear students, you have enough scope to shape your career in this exciting area of science and technology.

Fig. 1.1 A sword of Tipu Sultan made up of damascus steel.

1.3 Dimensions of the Physical World

To visualize / feel the size / dimension of different physical objects, moving from macrosystems → microsystems → nanosystems, pictorial comparison is given in the figure 1.2.

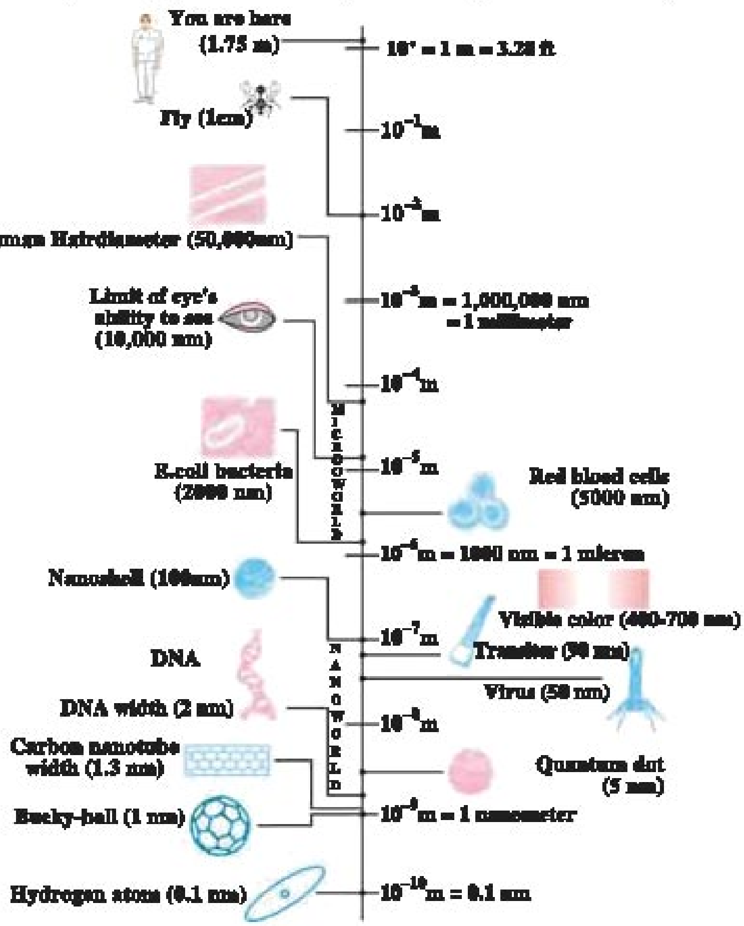


Fig. 1.2 Dimensional details of materials and things around us

We take 1 nanometer (nm) as reference to measure size of different objects in figure 1.2. Average height of a man (1.75 m) 1750,000,000 nm is too big compared to human hair with a diameter 50,000 nm. The size of Red blood cells and E-coli becteria are 5000 and 2000 nm, respectively. Transistor printed on IC (Integrated Circuit) is around 90 nm, while the size of virus is about 50 nm. Falling truly into nano-regime are the carbon nanotubes or bucky-balls. They are approximately 1 nm in size. The width of a typical DNA is around 2.0 nm. While the diameter of hydrogen atom is in sub-nano range (0.1 nm).

Size of human hair, becteria, red and white blood cells, fly ash, typically few thousands nm or greater, can be conveniently written in micrometer (10^{-6}m = 1 μm) scale.

The capacity of a normal human eye to see the smallest objects is 10,000 nm = 10 μm. It is thus obvious that in order to place atom or molecule to form specific nanostructure, microscope with very high magnification is required. In fact, due to advent of Scanning Tunneling Microscope (STM) and Atomic Force Microscope (AFM) arrangement of atom and molecules can be done efficiently while developing desired nanostructures.

1.4 Nanotechnology Plays by Different Rules

The prime goal of nanotechnology is to design nanostructures or nanoparticles for specific applications. It also provides a bridge between bulk or macro materials with atomic and molecular structures. Unlike the top-down approach, where methods for manufacturing involve the construction of parts through carving, cutting, molding, etc., special techniques are required for synthesis of nanomaterials. Depending upon types of atoms or molecules involved in the process, there are several methods available. These involve grinding (ball-mill) methods, use of thermal plasma, inert-gas condensation technique, wet-chemical technique or chemical solution deposition etc..

Another striking feature of nanostructures is their size and shape dependent on physical properties. Whereas bulk materials have almost constant properties regardless of their size and shape under the given physical conditions. An important parameter that determines the functioning of a nanomaterial is the surface area (SA) to volume (V) ratio. It is known that the reaction takes place at the surface of a chemical or material. The greater the surface area for the same volume, the greater is the reactivity. For nanostructured materials SA to V ratio, (i.e. SA/V) is large, which improves the reactivity drastically. This is the reason for showing different physical properties by the same material at the nanoscale.

Activity : 1

Take two cubes of length 1 unit and 10 unit respectively. Using the given formula calculate the following :

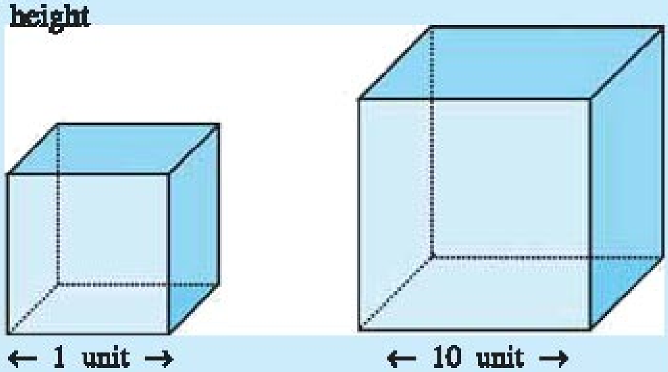
(i) Total surface area (SA) = length × breadth × number of sides

(ii) Volume (V) = length × breadth × height

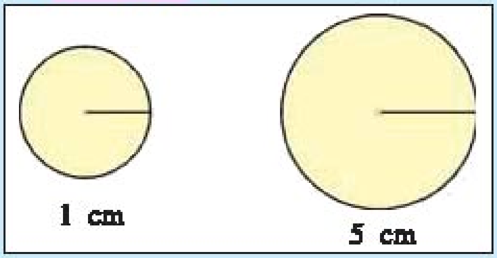
(iii) Ratio, $\frac{SA}{V}$

Question :

Which cube has a large $\frac{SA}{V}$?



Activity : 2



Find $\frac{SA}{V}$ for two spheres with radii 1 cm and 5 cm, respectively and give your conclusion.

Activity : 3

Why sugar granules (or powdered sugar) dissolve faster in water than a sugar-cube ? How thousands of folds and subfolds in the small intestine help in digestion ?

Further, due to large surface area to volume ratio, friction and sticking effects are also very important in nanomaterials. Nanomaterials with same dimensions but with different structures may show different physical properties. Also, as already mentioned, forces among nanoparticles are determined by the laws of quantum mechanics rather than the classical Newtonian laws of motion.

Truly, "Nanotechnology plays different rules !"

1.5 Fundamental Carbon-based Nanostructures

Carbon forms the backbone of biology of life on earth. This is in the form of complex molecules bonded with other elements, especially, oxygen, hydrogen and nitrogen (e.g. nucleic acid, enzymes, proteins, carbohydrates, etc.). It is also a major constituent in the conventional sources of energy. Further, materials containing carbon, exhibit a wide spectrum of properties. These properties are due to the following fundamental reasons :

First, carbon atom can bond with many different types of atoms including other carbon atoms by forming covalent bonds at a time. This helps to form long chains of atoms. This characteristic results in varieties of carbon allotropes; namely diamond, graphite, graphene, amorphous and glassy carbon and fullerenes, all showing different properties. Second, and most important, property of carbon is that it bonds strongly to other carbon atoms, by sharing different number of electrons. In fact, this strong cohesion is responsible for most stable biochemical compounds necessary for life. This is the reason why carbon is considered as a basis for the chemistry of life.

Due to versatile character of the carbon, we shall now discuss its nano-scale allotropes.

Fullerene :

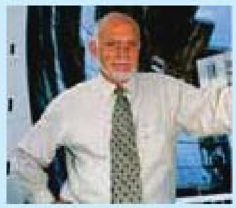
The common name for carbon-based nanostructures is 'Fullerene'. Fullerene is any molecule composed of carbon in the form of hollow sphere, ellipsoid or tube. Fullerenes are similar in structure to graphite, which is composed of stacked graphene

Fig. 1.3 Carbon Fullerene (C_{60})

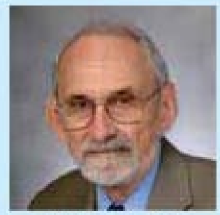
(a monolayer of graphite) sheets of interlinked pentagonal, hexagonal, and sometimes heptagonal rings. The fullerene was discovered by Robert F. Curl, Jr. Harold W. Kroto, James Heath, Richard E. Smalley and Sean O'Brie in 1985, through their mass spectrograph experiment. It was made up of 60 carbon atoms (C_{60}) in a dome-shaped hollow sphere (figure 1.3). The suffix "ene" in the word fullerene indicates that each C-atom is covalently bonded to three atoms with one "double - bond".

For Information Only

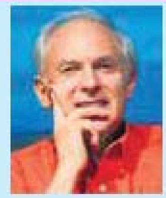
Jr. H. W. Kroto, R. E. Curl and R. E. Smalle were awarded Nobel Prize in 1996 in Chemistry for their work on Fullerenes.



R. E. Curl



R. E. Smalle



Jr. H. W. Kroto

Bucky-ball

Fullerene was named after Richard Buckminister Fuller, an architect known for his design of geodesic domes similar in shape to spherical C_{60} molecule. Since spherical fullerenes resemble to the football used in Association Football, they are also known as "bucky-ball" (figure 1.3). It is about 1nm in diameter.

Existence of fullerene is now identified naturally in candle soot and lightning discharge in the atmosphere. Recently, in 2010, scientists in NASA have found C_{60} present in a cloud of cosmic dust surrounding to a star 6500 light years away. According to one belief, bucky-balls that from outer space have provided seeds for life on Earth !

Bucky-balls with different numbers of C-atoms, C_{60}, C_{70}, C_{76}, C_{86} are also reported with smallest cluster of C_{20} to largest C_{540}.

Bucky-balls are extremely strong. However, due to special bonding among C-atoms, they can easily trap other atoms or molecules. Their purification is therefore a challenge to scientists and hence they are costly.

For Information Only

- In 2007, bucky-ball of Boron atoms, B_{80}, has been reported.
- Bucky-ball C_{20} doped with very few metal atoms, called metallofullerenes, are also prepared.

Carbon nanotubes

Carbon nanotubes are cylindrical fullerenes. In a sense, they are bucky-balls without the ends closing, which form long tube - like structure. Nanotubes of micrometers to millimeters in length are possible. The carbon nanotube derived from bucky-ball is also called a "bucky-tube". In the year 1991, a scientist of NEC laboratory, Sumio Tijima, prepared and explained the nanotube structure. Following figure 1.4 conceptualize how nanotube is constructed by stitching the bucky - balls.

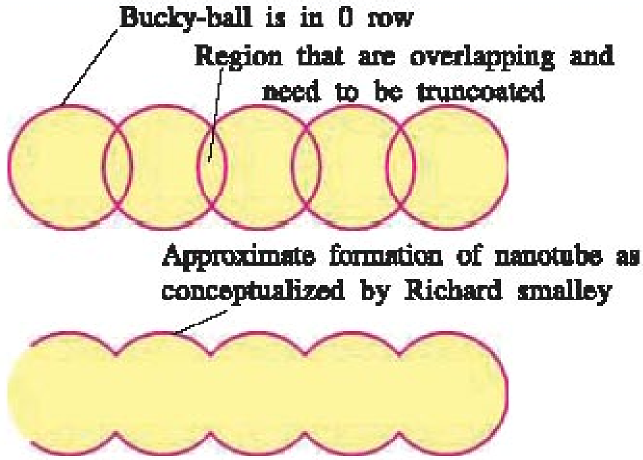


Fig. 1.4 Conceptualization of a Carbon Nanotube

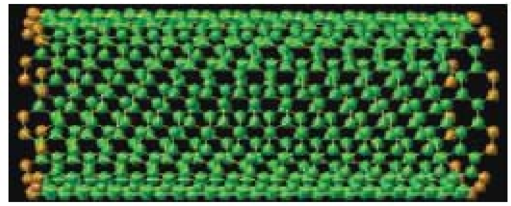


Fig. 1.5 Single Walled Nanotube (SWNT)

Nanotubes can be found with either closed-ends or open-ends. Nanotubes with reducing diameter (thickness) towards one of the ends can also be designed. Nanotubes with single cylinder (Figure 1.5), called Single Walled Nanotube (SWNT), and multiple concentric nano-cylinders with varying diameters; called Multi-Walled Nanotube (MWNT) can also be obtained (Figure 1.6).

Fig. 1.6 Multi-Walled Carbon Nanotube (MWNT)

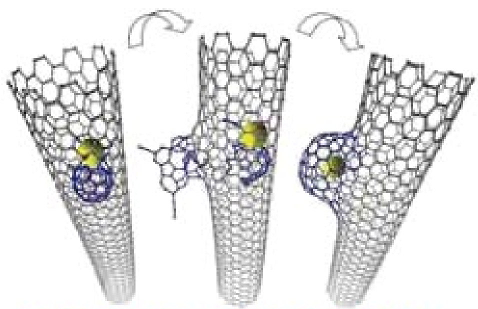


Fig. 1.7 Carbon nanotube - nanobud

Carbon nanobuds

Carbon nanobuds are newly discovered allotrope of carbon in which fullerene 'buds' are covalently attached to the outer part of the carbon nanotubes. This hybrid material has mixed properties of both fullerenes and nanotubes required for some special applications (figure 1.7).

1.6 Properties of Nanotube

These cylindrical carbon molecules have novel properties, making them potentially useful in many basic research and technological applications. A few physical properties of carbon nanotube are therefore listed below :

(1) Tensile and Compressive Strength : Their tensile strength is enormously large compared to many bulk materials including steel. This strength results from the covalent sp^2 bonds between carbon-carbon atoms. For example, a MWNT has tensile strength of 63×10^9 pascal (Pa) which is equivalent to having a mass of 6422 kg on a wire with 1 mm^2 of cross-section ! However, under excessive tensile strain nanotubes show permanent deformation. Compared to their tensile strength, compressive strength is low. Also, along the radial direction nanotubes are much softer, permitting bending like a rubber-tube.

(2) Hardness : Hardness of a standard SWNT is about 25×10^9 Pa, while its bulk modulus is higher than the diamond. The C_{60} fullerenes in crystalline form, known as 'Fullerites' are prepared under high-pressure and high-temperature conditions. They have remarkable mechanical properties, and hence, they are also named as 'Ultrahard Fullerites'.

(3) Electrical : Metallic nanotubes can carry electric current of 10^9 Ampere per cm^2 cross-section of the tube, which is 1000 times more than conducting copper metal. MWNT also show superconductivity upto the temperature of 12 K.

(4) Thermal : The carbon nanotubes have good thermal conductivity along with their length. For example, SWNT has thermal conductivity of 3500 $\frac{W}{mK}$. While the same for copper is only 385 $\frac{W}{mK}$ at room temperature. Interestingly, along the axis of the tube, nanotubes are good insulators. The thermal stability in vacuum is upto 3100 K, but only 1000 K in air.

1.7 Glimpses of The Benefits of Nanotechnology to Mankind

Eversince the production of first fullerene, the science of nanostructured designing evolve dramatically. As a result, we are able to harvest following benefits of the nanotechnology and many more to be realized in near future.

The major areas where nanotechnology can bring revolution to mankind are as follows :

Health Sector :

Higher functional efficiency of nano-devices results into better, cheaper and faster diagnostics and drug applications. Accurate and precise diagnosis improves medical treatment. It is possible to design a nano-drug which acts only at the infected site in our body, thus it reduces the side effect to other metabolic functions. For instance, anticancer nano-drug can be transported to cancerous cells, and upon excitation through laser beam, these nanodrugs are heated to destroy cancerous cells. Carbon nanotubes and their polymer nano-composites are suitable scaffold materials for bone cell proliferation and bone formation.

Energy resources :

Due to tunable electrical and optical properties, specially designed nano - materials can interchange electricity and light with minimum energy loss. They are more efficient than any of the conventional devices. Carbonic solar cells and hydrogen fuel cells will be shortly commercialized. Automobile engineering will improve to design lighter, stronger and fuel efficient vehicles. A paper thin sheet of cellulose infused with carbon nano - tubes act as highly efficient battery.

Security :

Due to lighter yet stronger mechanical properties of nanomaterials, they have found large applications in security. They are now used to construct light and strong battle tanks, spacecrafts, bridges, cranks, etc. Weaving them into clothes to create bulletproof clothing is possible. Since nano-particles have size - dependent melting point, they have found applications in industry as thermal security devices. Large structure of carbon nanotubes are used for thermal management of electronic circuits.

Other :

Research shows that ultrafast computing systems are possible with nanotechnology. Highly sensitive chemical sensors are possible which detect even a single molecule among different billion molecules. Nano-aluminum molecules are chemically so reactive that they are used to control explosions causing minimum collateral damage. Water purification using the nanotechnology is beneficial compared to current techniques. Many cosmetic products are now prepared based on the nanotechnology.

1.8 Importance of Nanotechnology

Various properties of materials such as electronics, thermal, mechanical, optical and chemical have been vastly improved at the nanoscale. Therefore it is possible to achieve exceptional performance in components and devices. Tunable chemical property is the great thrust in biological and medical sciences. Almost in every aspect of life, nanotechnology has important applications, however, there are certain points of concern. Large doses of specific nanodrugs have shown toxicity, which may cause damage to genetical functioning. Use of nanotechnology in designing more destructive weapons should be discouraged.

1.9 What one expect to improve in near future due to nanotechnology ?

Following are the main sectors in which we expect more improvement in near future due to nanotechnology :

(1) **Biotechnology :** Anti-aging drugs, Genetic engineering, Gene-therapy, Regenerative medicine, Synthetic genomics

(2) **Energy :** Renewable energy like biofuels, concentrated solar power, fusion power, Grid energy storage, nanowire battery, wireless energy transfer

(3) **Information Technology :** 3-dimensional (3D) printing, 3D optical data storage, Holographic data storage, optical computing, Quantum computing, Quantum Cryptography, Spintronics 3D - IC (Integrated circuit)

(4) **Material Science :** Superconductivity at high temperature, superfluidity at high temperature, multifunction structures, Programmable materials, Quantum dots

(5) **Robotics :** Nanorobotics, self-reconfiguring, modular robot, Swarm robotics

(6) **Others :** Projector phone, automatic train operation, driverless car, supersonic transportation, magnetic refrigeration

1.10 Some Important Areas of Nanotechnology

- Nanotubes and Bucky-balls
- Synthesis and characterization
- Nanocomposite
- Metallic nanotubes
- Bio and carbonic nano-sensors
- Nano energy storage devices

1.11 Future Challenges Using Nanotechnology

- Environmental problems can be solved.
- Efficiency of renewable sources can be greatly improved.
- It may help to grow life in outer space/planet.
- It helps in sustaining the planet for future generation.

What have you learnt ?

- 1 nm = 10^{-9} m
- Nanomaterials are manufactured by bottom-up approach, in which positionally - controlled atom-by-atom nanostructures are fabricated with desired properties.
- Size of nanoparticles range between 1-100 nm.
- Nanomaterials vastly differ in properties, their preparations, reactivity, in describing interactions among nanoparticles, etc. compared to corresponding bulk properties.
- Fullerene, Bucky-ball, graphene, metallolfullerences, nanotubes, nanobuds are some allotropes of carobn nanostructures.
- Carbon nanostructures show markedly different physical properties like high strength, high hardness, typical electrical and thermal conductivity, etc.
- Energy sector, security, biotechnology, information technology, Robotics, etc. are the areas which will improve greatly due to nanotechnology.

EXERCISE

1. Select the proper choice from the given multipule choices :

(1) 10 nanometer = ... meter

(A) 10^{-8} (B) 10^{-7} (C) 10^{-9} (D) 10^{-10}

(2) Size of nanoparticles range between .... nm.

(A) 100 to 1000 (B) 0.1 to 10 (C) 1 to 100 (D) 0.01 to 1

(3) Diameter of hydrogen atom is .... mn.

(A) 1 (B) 10 (C) 0.1 (D) 0.01

(4) Carbon atoms form .... bonds with other carbon atoms.

(A) covalent (B) ionic (C) metallic (D) hydrogen

(5) Fullerene or bucky-ball is made-up of .... carbon atoms.

(A) 100 (B) 20 (C) 75 (D) 60

(6) Thermal conductivity of standard SWNT along its length is .... $\frac{W}{mK}$.

(A) 3500 (B) 385 (C) 35,000 (D) 35

2. Answer the following questions in brief :

(1) What is nanoscience ?

(2) Mention the difference between bottom-up approach and top-down approach of synthesizing materials.

(3) Give two examples of use of nanostructures from earlier times.

(4) Name two microscopes which are used to develop nanostructures.

(5) What are carbon nanobuds ? Explain in brief.

(6) Give account of electrical properties of carbon nanotube.

(7) Name four energy sectors where nanotechnology is useful.

(8) Name important areas related to nanotechnology.

3. Write answer of the following questions :

(1) Explain how surface area to volume ratio is important for nanostructured materials.

(2) 'Carbon forms backbone of biology of life on earth'. Justify.

(3) Give detailed note on strength of carbon nanotubes.

(4) Write a note on thermal properties of carbon nanotubes.

(5) Explain how nanotechnology will be useful in health sector.

4. Answer the following questions in detail :

(1) Justify the statement 'Nanotechnology plays by different rules.'

(2) Write a detailed note on bucky-ball.

(3) Write a detailed note on a nanotube.

(4) Show how nanotechnology is important to us.

UNIT 2

LIGHT : REFLECTION AND REFRACTION

2.1 Introduction

The variety of objects in the world around us are visible due to the light entering into our eyes after its reflection from the object. We cannot see anything in a complete dark place.

Then ultimate question that arises is : "What is light ? How can it reaches to our eyes after the reflection from the object ?"

Light is an electromagnetic radiation which produces sensation in our eyes. It enters into our eyes after being transmitted through the transparent medium.

In previous standard, you have studied about some of the aspects regarding the reflection and refraction of light. In this chapter you will study more about these properties of light.

2.2 Nature of Light and its Basic Properties

Dear students,

As intimated earlier, now you know that light is an electromagnetic radiation producing sensation in our eyes. The light waves, known to be electromagnetic waves, do not require any material medium for its propagation (**That is why they are also known as non-mechanical waves**) and travel with the speed of 3×10^8 m s^{-1} in vacuum. When such a wave travels through transparent medium, its speed decreases notably which depends upon the medium. The wave length of visible region ranging from 4×10^{-7} m to 8×10^{-7} m is very short compared to the size of the normal object. In such a situation light waves can be considered to be travelling along a straight line path joining one point to another.

A straight line path joining one point to another in the direction of propagation of light is known as ray of light and a group of such rays of light is known as beam of light.

For Information Only

When there is an obstacle in the path of motion of light, the light has a tendency to bend around it, which is known as diffraction of light. To explain this phenomenon of light, its wave nature is considered which you will study in higher standards.

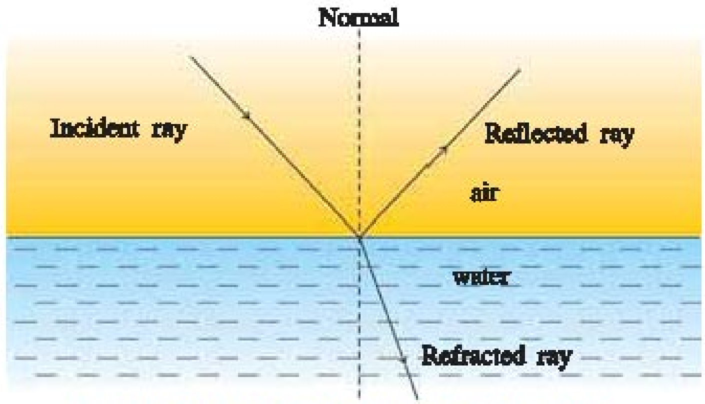


Fig 2.1 Reflection, refraction and absorption of light at water surface

As seen from Figure 2.1, when a ray of light is incident on a surface separting two transparent media (e.g. air and water), it may be reflected, refracted and absorbed partially.

The incident light gets reflected mostly from the completely polished shining plane surface whereas the light incident on the transparent medium is mostly refracted. The mirror through the reflection of light and a lens through the refraction in a transparent medium focus the light rays.

When many rays starting from one point meet at another point, after reflection or refraction, the image of the first point is said to be formed at this point. If the rays actually meet at some point then the image formed by them is real. If the rays do not meet actually, but appear to meet when extended backwards, the image is virtual. A real image of an object can be obtained on the screen while the virtual image cannot be obtained on the screen.

Thus, the image of an extended object with finite size can be obtained by collecting image points, corresponding to different points of an object.

2.3 Reflection of Light : Regular and Irregular Reflection of Light

Dear student,

As mentioned earlier, we can see the objects around us only due to the reflection of light from them. If it is not so, the world would have become dark !

A moon in a full swing could not be seen !

Thus, a phenomenon of returning the light from the surface of an object, when the light incident on it, is a reflection of light.

The reflection of light takes place in two ways : (i) Regular reflection (ii) Irregular reflection

(i) Regular reflection :

When a parallel beam of light is incident on shining plane or smooth surface, a beam remains parallel after reflection in a specific direction. Such reflection of light is called **regular reflection**. The reflection of light by a mirror is an example of regular reflection (Figure 2.2).

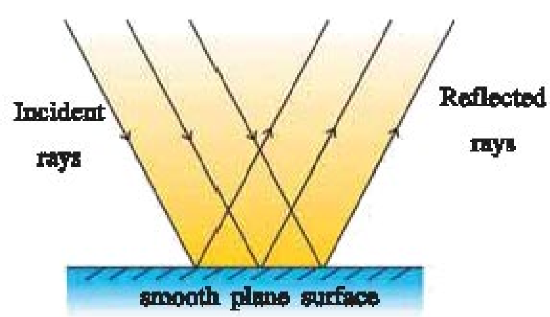


Fig. 2.2 Regular reflection of light

(ii) Irregular reflection : When a parallel beam of light is incident on rough or irregular surface, the beam does not remain parallel but spreads over wide region after reflection. Such a reflection of light is known as an **irregular reflection** (Figure 2.3).The object around us such as book, chair, table etc. can be seen as a result of irreguler reflection of light.

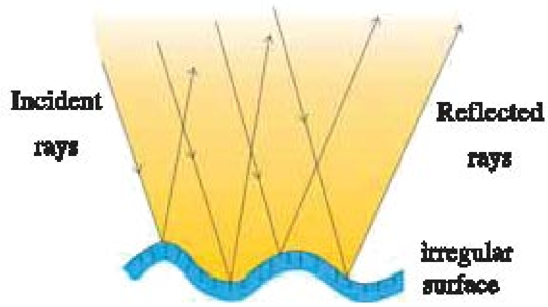


Fig. 2.3 Irregular reflection of light

2.4 Laws of Reflection

Before we state the laws of reflection, let us remind the terms associated with them.

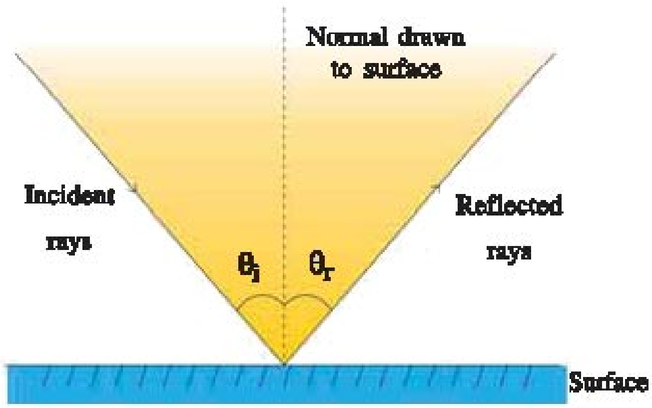


Fig. 2.4 Reflection of light

Angle of incidence (θ_i) :

The angle made by an incident ray with the normal drawn at the point of incidence is known as angle of incidence (θ_i).

Angle of reflection (θ_r) :

The angle made by reflected ray with the normal drawn at point of incidence is known as angle of reflection (θ_r).

In figure 2.4, θ_i represents angle of incidence and θ_r represents angle of reflection. The laws of reflection using above terminology are stated as under :

(1) The angle of incidence is equal to angle of reflection i.e. $\theta_i = \theta_r$.

(2) The incident ray, the normal to the mirror at the point of incidence and the reflected ray all lie in the same plane.

The laws of reflection are equally applicable to plane as well as spherical mirrors. Moreover, they are also applicable to regular as well as irregular surfaces.

2.5 Reflection by A Plane Mirror

As shown in Figure 2.5, an extended object AO of height h represented by an arrow is kept in front of a plane mirror MM' at a distance u.

Here, each small portion of an extended object facing the mirror acts like a point source, the position of an image obtained in this way is located by the following way :

The incident rays AN and AQ are drawn from points A of the object.

The corresponding reflected rays NA and QR are drawn applying laws of reflection.

As the reflected rays NA and QR are divergent rays, they cannot meet in front of the mirror, but they intersect at A' in extending them behind the mirror which is shown in Figure 2.5. Thus A' is the virtual image of A. In the similar way, all the point sources between A and O will form corresponding images between A' and I.

It is clear from Figure 2.5 that

(1) A plane mirror forms virtual and erect image A'I at a distance v from it.

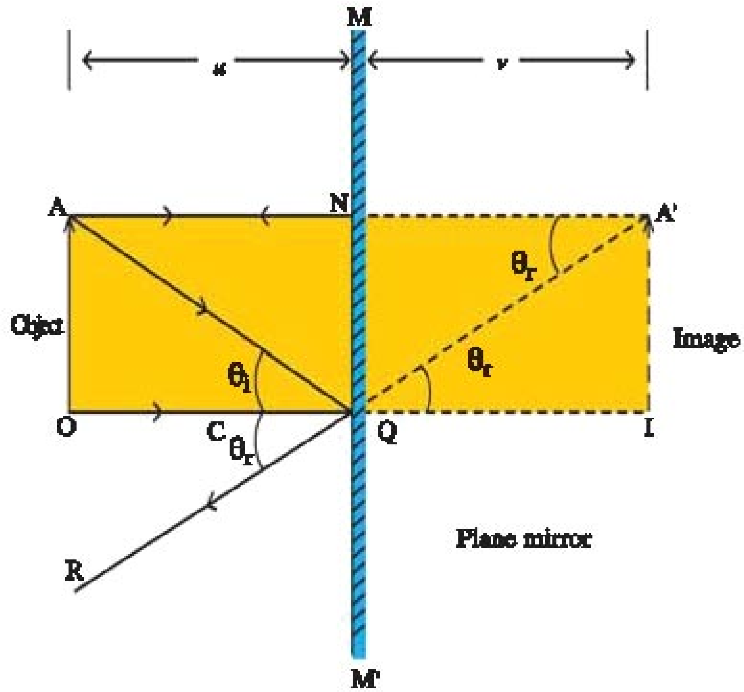


Figure 2.5 Reflection by a plane mirror

(2) The image A'I is formed at the same distance behind the mirror as that of an object AO kept in front of mirror.

(3) The size (height) of an image is same as the object but is laterally inverted.

Activity : 1

Stand in front of a plane mirror in your house and observe the image. Now raise your left hand and observe the image in a mirror.

The virtual, erect and of same size as the object, will be obtained at the same distance as the object behind the mirror. When you raise your left hand, the image appears to raise the right hand. This type of image obtained from the plane mirror is called **laterally inverted** image.

2.6 Reflection by Spherical Mirror

The spherical mirrors are formed by cutting the circular cross section of spherical shell whose inner or outer curved surface are reflecting.

A spherical mirror having inner curved reflecting surface is known as concave mirror.

A spherical mirror having outer curved reflecting surface is known as convex mirror.

In order to study the reflection by spherical mirror, we need to understand the definitions of a few necessary terms.

For this, see Figure 2.6 showing reflection by spherical mirror.

Radius of curvature (R) and centre of curvature of mirror (C) : The radius of a spherical shell from which the mirror is curved, called radius of curvature (R) of mirror and the centre of this spherical shell is called centre of curvature (C) of mirror.

Remember that centre of curvature is not a part of spherical mirror.

Pole : A centre of reflecting surface of a spherical mirror is called pole (P) of the mirror.

Principal axis : An imaginary line passing through pole (P) and centre of curvature (C) of mirror is called principal axis of mirror.

Aperture : The diameter of the reflecting suface of the mirror is known as aperture of the mirror.

Principal focus : The point on the principal axis where the parallel rays meet after the reflection from concave mirror or appear to meet after reflection from convex mirror, is called principal focus (F) of the mirror.

Focal length : The distance between pole (P) and principal focus (F) of mirror is called focal length *(f)*.

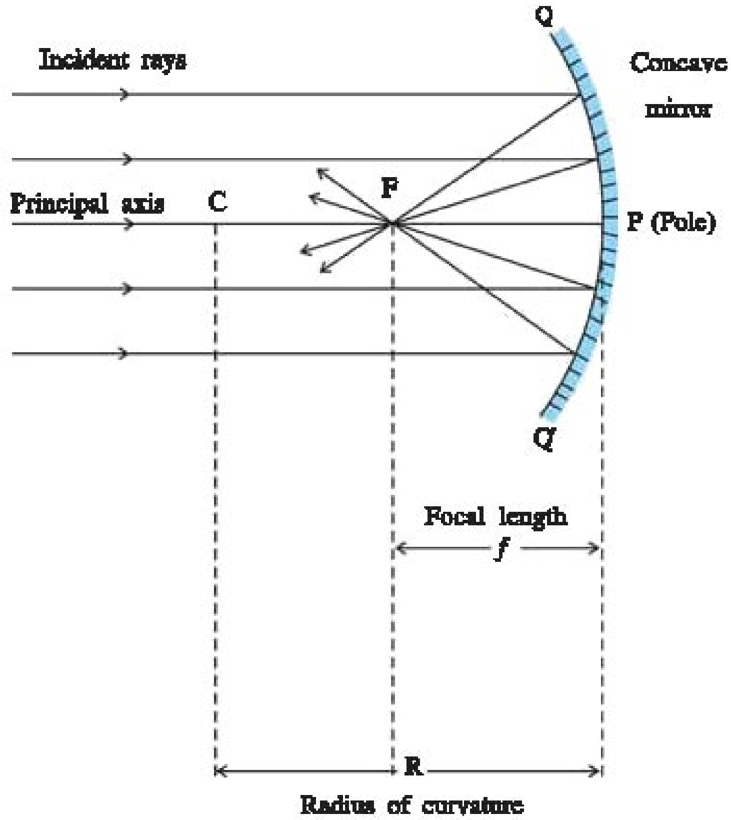


Fig. 2.6 Reflection by spherical mirror

The image of an object formed by spherical mirror can be located by constructing a ray diagram. For this, we may arbitarily consider a large number of rays emanating from a point, but for the sake of clarity of ray diagram, it is more convenient to consider only two rays because, at least two rays are required to locate the position of an image of point object.

The rays reflected from spherical mirror in different ways are represented by Figure 2.7 to 2.10.

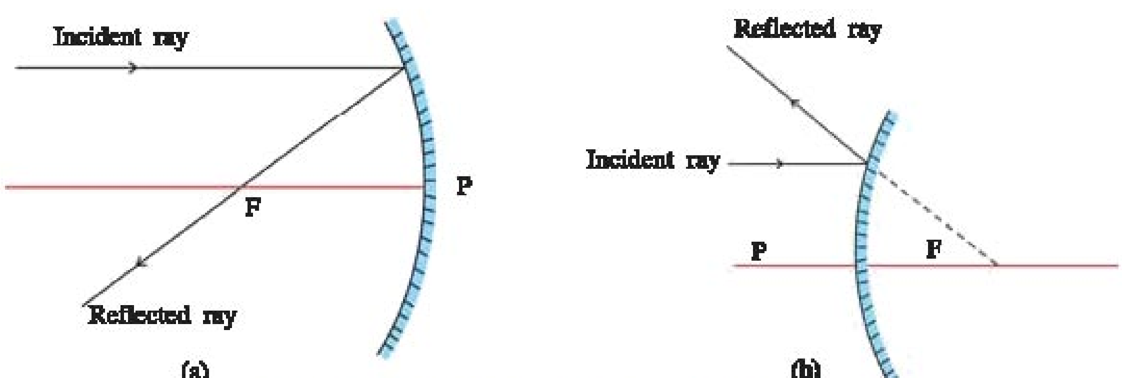


Fig. 2.7 Ray incident parallel to principal axis

A ray parallel to the principal axis after reflection will pass through the principal focus (F) in case of a concave mirror or appears to diverge from the principal focus (F) in case of a convex mirror (Figure 2.7).

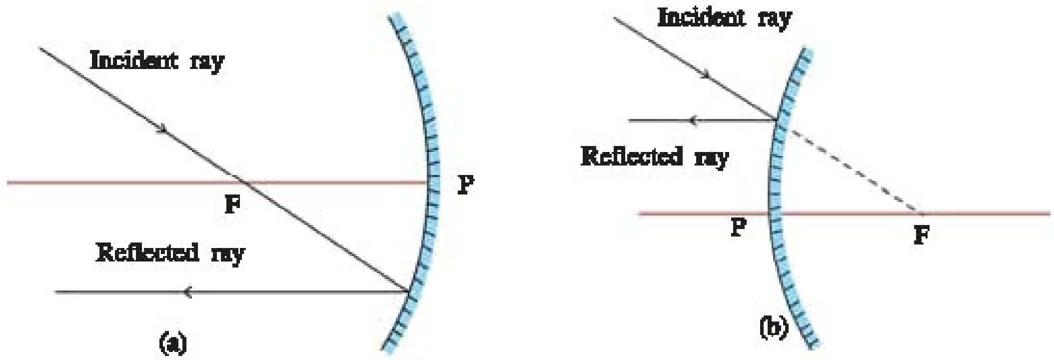


Fig. 2.8 (a) Ray passing through principal focus of concave mirror
(b) Ray directed towards principal focus of convex mirror

A ray passing through the principal focus (F) of a concave mirror or a ray which is directed towards the principal focus (F) of a convex mirror will emerge parallel to principal axis (Figure 2.8).

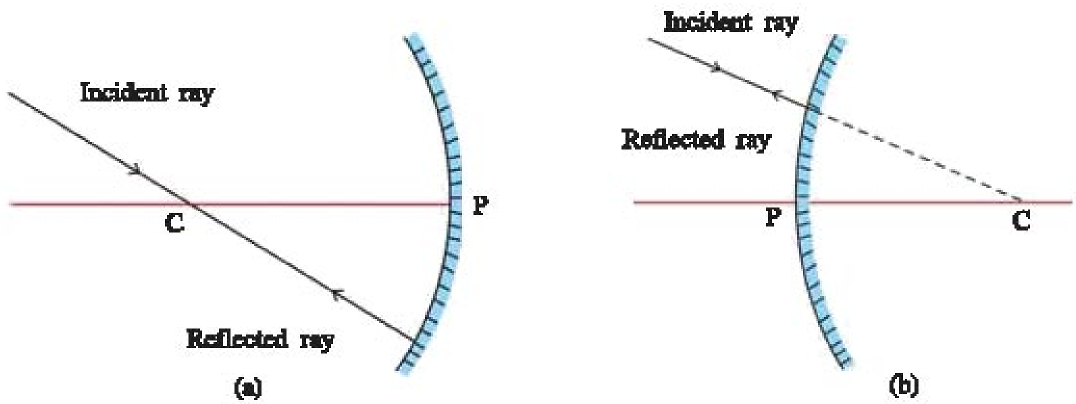


Fig. 2.9 (a) A ray passing through centre of curvature (C) of concave mirror
(b) A ray directed toward centre of curvature (C) of convex mirror

A ray passing through the centre of curvature of a concave mirror or directed towards the centre of curvature of a convex mirror after reflection, is reflected along the same path.

Fig 2.10 a ray incident obliquely to principal axis towards pole of a mirror

A ray incident obliquely to the principal axis towards pole (P) of a concave or a convex mirror is reflected obliquely follows the laws of reflection.

2.7 Image Formation by Concave Mirror

The images formed by a concave mirror MM' of a small aperture for different positions of object AB is shown in Table 2.1.

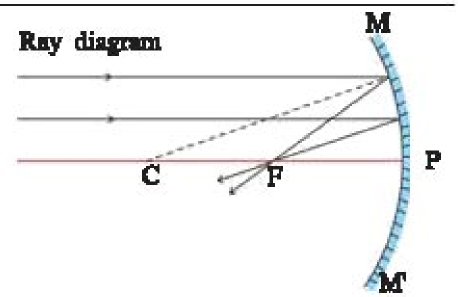
Table 2.1 Image Formation by Concave Mirror

(1) **Position of an object :** At infinity

Position of image : At focus (F)

Nature : Real and inverted

Size : Highly diminished (Pointlike)

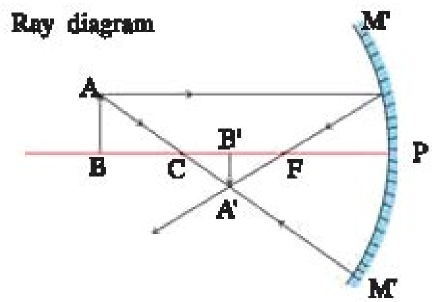


(2) **Position of an object :** Beyond centre of curvature (C)

Position of image : Between centre of curvature (C) and focus (F)

Nature : Real and inverted

Size : Diminished (small)

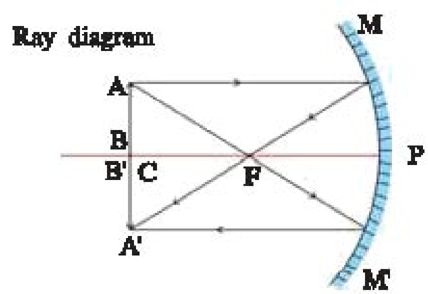


(3) **Position of an object :** At centre of curvature (C)

Position of image : At centre of curvature (C)

Nature : Real and inverted

Size : Same as object

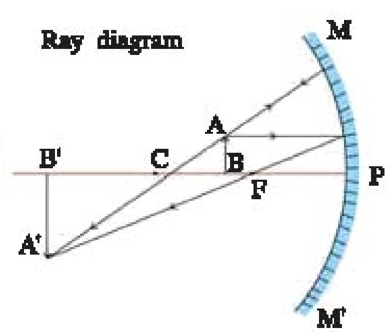


(4) **Position of an object :** Between centre of curvature (C) and principal focus (F)

Position of image : Beyond the centre of curvature (C)

Nature : Real and inverted

Size : Magnified (enlarged)

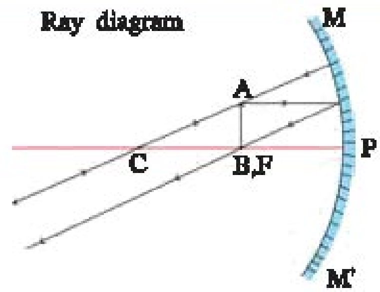


(5) **Position of an object :** At principal focus (F)

Position of image : At infinity

Nature : Real and inverted

Size : Highly magnified

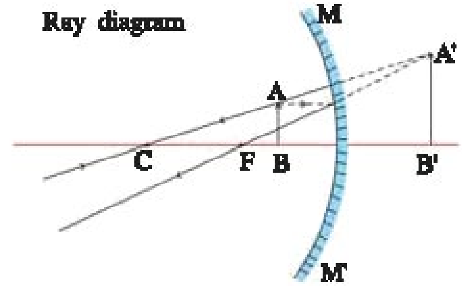


(6) **Position of an object :** Between pole (P) and principal focus (F)

Position of image : Behind the mirror

Nature : Virtual and erect

Size : Magnified (enlarged)



Activity : 2

Hold a concave mirror in your hand and direct its reflecting surface towards the Sun. Then direct the light reflected by a mirror on to a sheet of paper held close to mirror. Move the sheet of paper back and forth until the bright sharp spot is obtained. What do you observe ?

As the paper sheet is at the focus of concave mirror, the light from the Sun is converged at the focus of the mirror which produces a sharp bright spot. The heat produced due to the concentration of sunlight ignites the paper. The distance of spot on paper from concave mirror gives its approximate focal length.

Activity : 3

Draw a neat ray diagram for the object having 1 cm height placed at 6 cm distance from the concave mirror of focal length 4 cm. Take any two rays mentioned in Section 2.6 to locate the image. Compare your ray diagram with that given in Table 2.1. You will obtain real, inverted and having height twice to that of an object at 12 cm distance from the mirror (Figure 2.10.1)

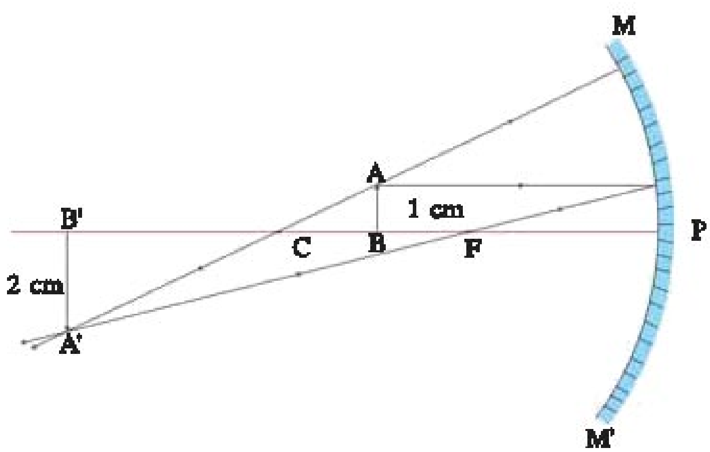


Fig. 2.10.1 (Ray diagram) Image formation by concave mirror

2.8 Image Formation by Convex Mirror

The image formed by a convex mirror MM' of a small aperture for different positions of object is shown in Table 2.2.

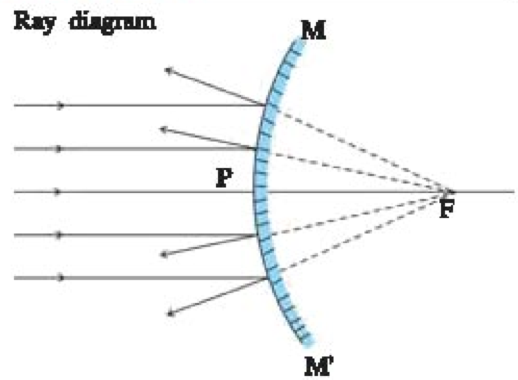
Table. 2.2 Image Formation by Convex Mirror

(1) **Position of an object :** At infinity

Position of image : At focus (F) behind mirror

Nature : Virtual and erect

Size : Highly diminished (point like)

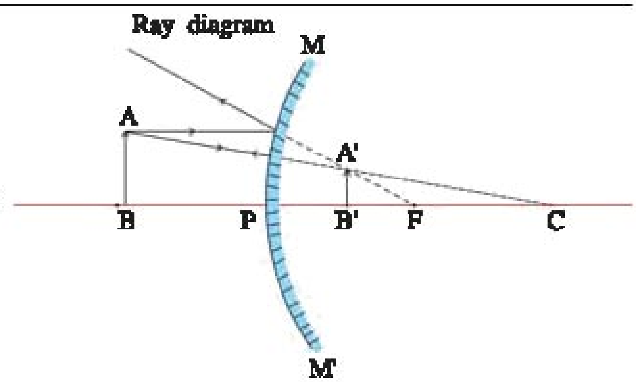


(2) **Position of an object :** Between pole (P) and infinity

Position of an image : Between pole (P) and focus (F) behind mirror

Nature : Virtual and erect

Size : Diminished (small)



Activity : 4

Hold the convex mirror in one hand and hold pencil with its tip pointing upward in other hand. View its image in the mirror. Is the image erect or inverted ? Is the image magnified or diminished ? Now when a pencil is moved away from the mirror, what will be the change in the position and size of an image ?

The erect and diminished image of a pencil is obtained by a convex mirror. On moving the pencil away from the mirror, the size of an image goes on decreasing and it moves toward the focus.

The full length image of a tall building or a tree can be viewed by a convex mirror. One such convex mirror is fitted on the wall of Agra fort. When you visit the Agra fort, try to observe the full-length image of distant tall building.

2.9 Cartesian Sign Convention for Reflection by Spherical Mirror

As shown in Figure 2.11, the pole (P) of a mirror is taken as the origin of cartesian co-ordinate system. The principal axis of the mirror is taken as X-axis and the axis drawn perpendicular to principal axis at pole (P) is considered as Y-axis.

The following sign convention is used to represent the distances related with the reflection by spherical mirror.

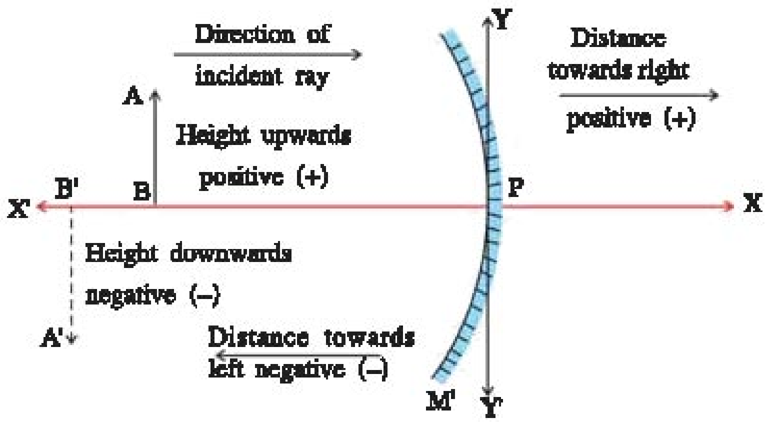


Fig. 2.11 Cartesian sign convention for spherical mirror

(1) The object is on the left side of a mirror means the light rays are incident from the left side of a mirror.

(2) All the distances are measured from the pole (P) of a mirror parallel to the principal axis.

(3) The distances measured in the direction of incident ray (toward right) are taken positive.

(4) The distances measured in the direction opposite to incident ray (toward left) are taken negative.

(5) The height measured upward and perpendicular to principal axis is taken positive.

(6) The height measured downward and perpendicular to principal axis is taken negative.

2.10 : Mirror Formula and Magnification of Image

The formula which gives relation between object distance (u), image distance (v) and focal length (f) of mirror is known as mirror formula.

As shown in Figure 2.12, the object AB of height h is placed at a distance u from the pole (P) in front of a concave mirror of small aperture just beyond centre of curvature (C). Therefore, its real, inverted and diminished image B'A' of height h' will be formed at a distance v in front of the mirror.

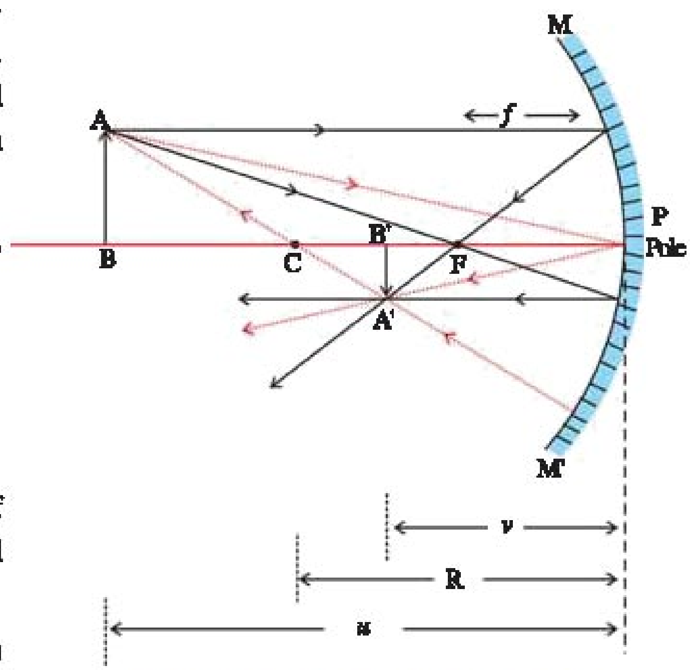


Fig. 2.12 Reflection by a concave mirror

According to Cartesian sign convention,

Object distance (PB) = $-u$

Image distance (PB') = $-v$

Focal length (PF) = $-f$

Radius of curvature (PC) = $-R$.

It is clear from the geometry of Figure 2.12 that right angle ΔABP and $\Delta A'B'P$ are similar.

(See the following figure to understand.)

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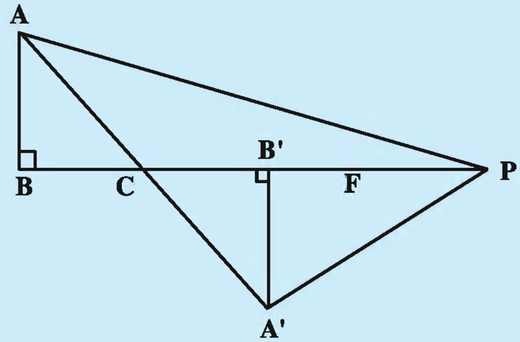


$$\therefore \frac{A'B'}{AB} = \frac{PB'}{PB} = \frac{-v}{-u}$$

$$\therefore \frac{A'B'}{AB} = \frac{v}{u} \qquad (2.10.1)$$

In the similar way Δ ABC and Δ A'B'C are similar

$$\therefore \frac{A'B'}{AB} = \frac{CB'}{CB} \qquad (2.10.2)$$

From Figure 2.12

CB' = PC − PB' = −R − (−v) = −R + v (Do not forget to use sign convention)

and CB = PB − PC = − u − (− R) = − u + R

∴ From equation (2.10.2)

$$\frac{A'B'}{AB} = \frac{-R + v}{-u + R} \qquad (2.10.3)$$

Comparing equation (2.10.1) and (2.10.3) $\frac{v}{u} = \frac{-R + v}{-u + R}$

$\therefore -uv + Rv = -Ru + vu$

$\therefore Rv + Ru = 2\,uv$

$\therefore R\,(v + u) = 2\,uv$ (2.10.4)

Dividing equation (2.10.4) by Ruv on both the sides, $\frac{v + u}{uv} = \frac{2}{R}$

$$\therefore \frac{1}{v} + \frac{1}{u} = \frac{2}{R} \qquad (2.10.5)$$

Now when the object is placed at an infinite distance, its image will be formed at the principal focus (F).

∴ Object distance $u = \infty$ and image distance $v = f$

Putting these values in equation (2.10.5)

$$\frac{1}{f} + \frac{1}{\infty} = \frac{2}{R}$$

$$\therefore \frac{1}{f} = \frac{2}{R} \qquad \left(\because \frac{1}{\infty} = 0\right)$$

$$\therefore f = \frac{R}{2} \qquad (2.10.6)$$

This shows that the principal focus (F) is a mid point between pole (P) and centre of curvature (C) along principal axis.

Substituting the value of R from equation (2.10.6) into (2.10.5)

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f} \qquad (2.10.7)$$

This equation is known as **mirror formula.**

This mirror formula is true for both types of spherical mirrors for all the positions of object.

Magnification of an image

The ratio of height of image to the height of an object is known as magnification of an image which is denoted as m.

$$m=\frac{\text{Image height}}{\text{Object height}}=\frac{h'}{h} \qquad (2.10.8)$$

From figure 2.12,

$$\frac{A'B'}{AB}=\frac{PB'}{PB}$$ Where A'B' = Image height (h'), AB = object height (h)

PB' = Image distance (v), PB = object distance (u)

$$\therefore \frac{h'}{h}=\frac{-v}{-u}=\frac{v}{u} \qquad (2.10.9)$$

From equations (2.10.8) and (2.10.9) $m=\frac{v}{u}$

Now according to cartesian sign convention, A'B' = – h' and AB = h

$$\therefore \text{ Magnification } \therefore m=\frac{-h'}{h} \qquad (2.10.10)$$

Note that the object height (h) is always positive.

The image height (h') will be positive in case of erect image, hence its magnification will be positive.

The positive value of magnification represents virtual image of an object.

The image height (h') will be negative in case of an inverted image, hence its magnification will be negative.

The negative value of magnification represents real image of an object.

Now consider the case of a plane mirror.

In this case, Image height (h') = object height (h)

$\therefore m = +1$

Therefore, the image formed by a plane mirror is virtual, erect and of the same size as the object.

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

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

$\therefore v = -u$

This shows that the image formed by a plane mirror is at the same distance as the object but behind the mirror.

In case of plane mirror try to obtain the position of an image using mirror formula.

The following Table 2.3 shows the type and size of an image and the type of mirror corresponding to magnification value (*m*).

Table 2.3 Magnification and Type of Image and Mirror

Number	Magnification (*m*)	Type of image and its size	Type of mirror
1	+ 1	Virtual, erect and of same size as an object	Plane
2	– 1	Real, inverted and of same size as an object	Concave
3	> 1 and negative	Real, inverted and magnified	Concave
4	< 1 and negative	Real, inverted and diminished	Concave
5	> 1 and positive	Virtual, erect and magnified	Concave
6	< 1 and positive	Virtual, erect and diminished	Convex

Verify this table by comparing the images formed by concave and convex mirror given in Table 2.1 and 2.2.

Illustration 1 :

Determine nature and size of image, and the type of mirror for the image formed by mirrors corresponding to magnification values + 1, – 1, + 0.5, – 0.5 + 5.0 and – 5.0.

From the above Table 2.3, solution will be as under :

Number	Magnification (m)	Nature and Size of Image	Type of Mirror
1	+ 1	Virtual erect and of same size as an object	Plane
2	– 1	Real, inverted and of same size as an object	Concave
3	+ 0.5	Virtual, erect and diminished	Convex
4	– 0.5	Real, inverted and diminished	Concave
5	+ 5.0	Virtual, erect and magnified	Concave
6	– 5.0	Real, inverted and magnified	Concave

Illustration 2

An object of 4 cm height is placed at a distance of 18 cm from concave mirror having focal length 12 cm. Find the position, nature and height of the image.

Solution : Object height $h = 4$ cm

Object distance $u = -18$ cm

Focal length $f = -12$ cm

From mirror formula, $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

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

$$\therefore \frac{1}{v} = -\frac{1}{12} + \frac{1}{18}$$

$$\therefore \frac{1}{v} = -\frac{1}{36}$$

$$\therefore v = -36 \text{ cm}$$

Magnification $m = -\frac{v}{u} = +\frac{36}{-18} = -2$

$$\therefore \text{From } m = \frac{h'}{h}$$

$$h' = m \times h = -2 \times 4 = -8 \text{ cm}$$

This forms real, inverted and enlarged image of an object beyond the centre of curvature (C) at 36 cm from the pole.

Illustration : 3

A convex mirror is fitted on an automobile with focal length of 3 m. If a vehicle behind is at a distance of 5 m, determine the position and nature of an image.

Solution : Object distance $u = -5$ m

Focal length $f = 3$ m

From mirror formula

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

$$\therefore \frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{3} + \frac{1}{5}$$

$$\frac{1}{v} = \frac{8}{15}$$

$$v = \frac{15}{8} = 1.875 \text{ m}$$

Here, v is positive and $v < u$

$\therefore \ m < 1.$

Therefore, virtual, erect and diminished image behind the convex mirror is obtained at a distance 1.875 m from the mirror.

2.11 Refraction of Light and Its laws

You have studied refraction of light from prism and rectangular glass slab in Standard 8.

When a ray of light enters oblique from one transparent medium to another transparent medium, its velocity changes due to which it gets deviated from its original direction at the surface separating two media. This phenomenon is called refraction of light.

Experiments show that the refraction of light occurs according to certain laws which are shown as under :

(1) The incident ray, the refracted ray and the normal to the surface separating two media at the point of incidence all lie in the same plane.

(2) The ratio of sine of angle of incidence to the sine of angle of refraction remains constant subject to certain situations. This law is known as Snell's Law of Refraction.

Remember that this law holds for a given colour (wave length) of light and for a given pair of media.

As shown in Figure 2.13, an incident ray PQ is incident at a point Q on the surface separating medium 1 and medium 2. QR is the ray refracted from the surface and MQN is the normal to the surface at the point of incidence Q.

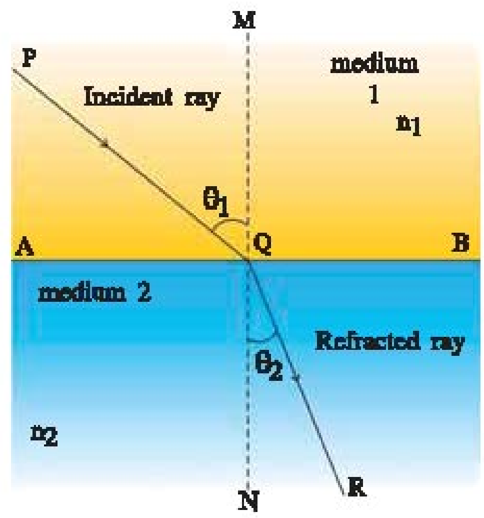


Figure 2.13 Refraction of light

From Figure 2.13,

$\angle$ PQM = angle of incidence (θ_1)

and $\angle$ RQN = angle of refraction (θ_2)

According to Snell's Law,

$$\frac{\sin\theta_1}{\sin\theta_2} = \text{constant} \qquad (2.11.1)$$

The constant in equation (2.11.1) is known as refractive index of medium 2 relative to medium 1 and is denoted as n_{21}.

$$\therefore n_{21} = \frac{\sin\theta_1}{\sin\theta_2} \qquad (2.11.2)$$

In terms of ratio of velocity of light in two media, the refractive index of light is represented as under :

The ratio of velocity of light v_1 in medium 1 to the velocity of light v_2 in medium 2 is called refractive index of medium 2 with respect to medium 1.

$$n_{21} = \frac{v_1}{v_2} \qquad (2.11.3)$$

In vacuum, light travels with the speed of 3×10^8 m s^{-1}. In air the speed of light is marginally less compared to that in vacuum. Therefore, in practice, the speed of light in air is considered same as that in vacuum.

The refractive index of the transparent medium with respect to vacuum is called an **absolute refractive index** of a medium. It is commonly known as refractive index.

Let n_1 = absolute refractive index of medium 1 n_2 = absolute refractive index of medium 2

v_1 = velocity of light in medium 1 v_2 = velocity of light in medium 2

and c = velocity of light in vacuum then

$$n_1 = \frac{c}{v_1} \text{ and } n_2 = \frac{c}{v_2}$$

$$\therefore n_{21} = \frac{n_2}{n_1} = \frac{c/v_2}{c/v_1}$$

$$\therefore n_{21} = \frac{n_2}{n_1} = \frac{v_1}{v_2} \qquad (2.11.4)$$

From equations (2.11.2) and (2.11.4), $\frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2}$

$$\therefore n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad ... (2.11.5)$$

The equation (2.11.5) is called general form of **Snell's Law.**

The absolute refractive indices of some useful material media are given in Table 2.4

Table 2.4 Absolute Refractive Indices of Some Material Media

(For Information Only)

Material Medium	Refractive Index	Material Medium	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	Dense flint glass	1.65
Kerosene	1.44	Ruby	1.71
Glycerine	1.47	Saphire	1.77
Normal glass and Benzene	1.50	Diamond	2.42

When a light ray travels from optically rarer to optically denser medium, it moves toward the normal and when it travels from optically denser to optically rarer medium it moves away from the normal.

Remember that optical denser and optical rarer property of media are related to their refractive indices. The optical denser medium has larger refractive index compared to optical rarer medium.

It is to be noted here that the medium that has larger mass density is not necessarily optically denser. For example, kerosene is optically denser than water as it is having larger refractive index (Table 2.5) though its mass density is less than that of water. (Generally, in practice mass density is considered as the density of a material.)

Illustration : 4

Light enters from air to glass having refractive index 1.5. What is the speed of light in glass ? The speed of light in vacuum is 3×10^8 m/s.

Solution :

Absolute refractive index of glass

$$n = \frac{c}{v} \qquad \text{and} \qquad c = 3 \times 10^8 \text{ m s}^{-1}$$

$$\therefore v = \frac{c}{n}$$

$$= \frac{3 \times 10^8}{1.5} \text{ m s}^{-1} \quad (n = 1.5)$$

$$= 2 \times 10^8 \text{ m s}^{-1}$$

Illustration : 5

A light ray enters from air to the water medium having the absolute refractive index 1.33. If the angle of refraction of light is 17° 30', what will be the angle of incidence at the surface seprating the two media ?

Take absolute refractive index of an air as 1.00.

Solution :

Taking air as medium 1 and water as medium 2,

$n_1 = 1$ $n_2 = 1.33$ $\theta_2 = 17^0\ 30'$

According to Snell's law

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\sin \theta_1 = 1.33 \times \sin 17^0\ 30'$$

The value of sin 17°30' is determined from the mathematical table of natural sine.

From the Table of natural sine

$$\sin 17^0\ 30' = 0.3$$

$$\therefore \sin \theta_1 = 1.33 \times 0.3 = 0.4$$

$\therefore$ From the table of natural sine

$$\sin 23^0\ 36' = 0.4007$$

$$\therefore \theta_1 = 23^0\ 36'$$

$\therefore$ Angle of incidence = 23°36'

2.12 : Refraction of Light Through Rectangular Glass Slab

A line drawn on a piece of paper appears to be raised or shifted up when a glass slab is placed on it. Similarly any thing lying on the bottom of a swimming pool appears to be raised. These facts result due to the phenomenon of refraction of light.

As shown in Figure 2.14,

A light ray AB is incident at angle θ_1 at point B on the surface PQ of a glass slab. After the refraction from point B, a refracted ray BC is incident at point C on surface RS at an anlge θ_3 and emerges as a ray CD from the glass slab.

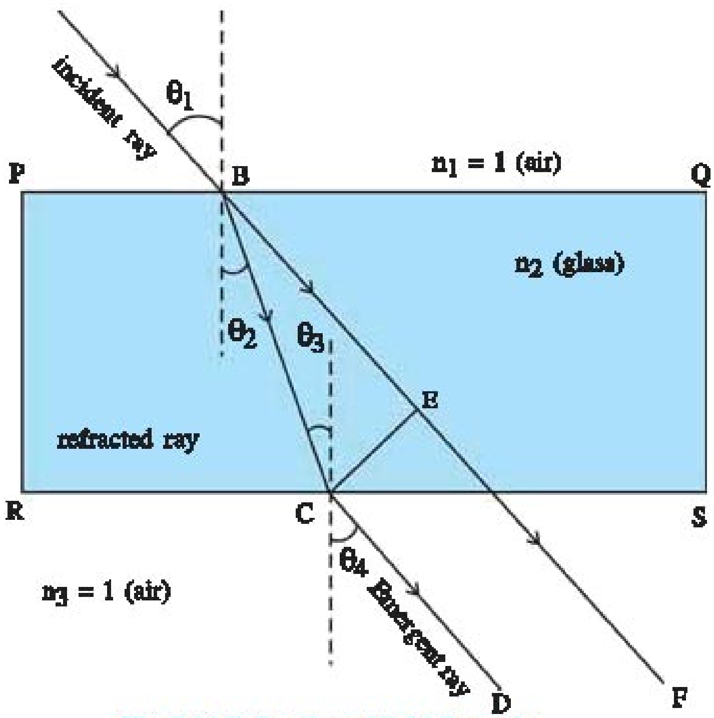


Fig. 2.14 Refraction of light through rectangular glass slab

Let us determine the direction of an emergent ray using the laws of refraction.

Here, n =1, for the medium of an air at the surface PQ.

Therefore, from Snell's Laws $n_1 \sin\theta_1 = n_2 \sin\theta_2$

$$\therefore \quad \sin\theta_1 = n_2 \sin\theta_2 \quad (\because n_1 = 1) \qquad (2.12.1)$$

Similarly for the surface RS parallel to PQ,

$$n_2 \sin\theta_3 = n_3 \sin\theta_4$$

$$\therefore n_2 \sin\theta_3 = \sin\theta_4 \ (n_3 = 1 \text{ for an air})$$

$$\therefore n_2 \sin\theta_2 = \sin\theta_4; \ (\theta_2 = \theta_3 \text{ as they are alternate angles}) \qquad (2.12.2)$$

From equation (2.12.1) and (2.12.2)

$$\sin\theta_1 = \sin\theta_4$$

$$\therefore \ \theta_1 = \theta_4 \qquad (2.12.3)$$

It is clear from Figure 2.14 and equation (2.12.3) that the emergent ray CD travels in the same direction as an incident ray AB, but it is displaced by a perpendicular distance CE.

Thus, when a ray of light is refracted from two parallel refracting surfaces, the emergent ray is displaced from the direction of incident ray. This kind of displacement is called **lateral shift**. The amount of lateral shift depends upon perpendicular distance between two parallel refracting surfaces as well as upon the angle of incidence and refractive index of medium.

> **Activity : 5**
>
> Place a rectangular glass slab on a piece of paper and draw outline of the slab with a pencil. Fix two pins on one side of a slab. Fix other two pins on another side of slab such that all four pins appear to be on a straight line. Trace the path of a ray after removing pins and slab. Take other rectangular glass slabs of different size and prove that the extent to which lateral shift produced depends upon the perpendicular distance between two parallel refracting surface.

2.13 Image Formation by Convex and Concave Lens

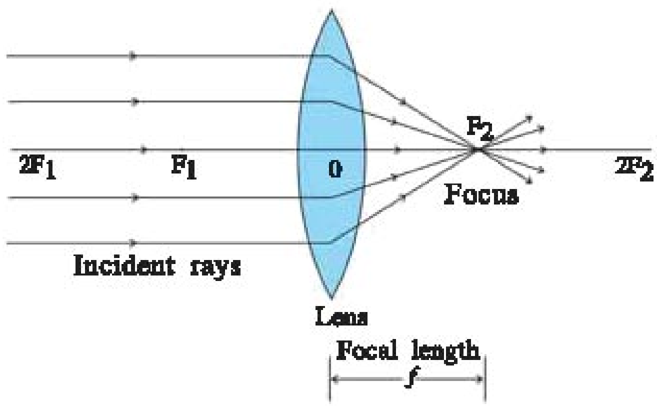


Fig. 2.15 Image formation by convex lens

Let us remember the definition of some of the terms associated with the lens to understand the image formation by lens.

For this consider the Figure 2.15 showing the image formation by convex lens.

The centres of the respective spheres of which the surfaces of a lens can be considered as part, are the centres of curvature of the respective surfaces.

Radius of Curvature (R)

The radii of spheres from which the curved surfaces are formed are known as radii of that surface of the lens. The radii of the curvatures of the two surfaces are R_1 and R_2.

Principal Axis of A Lens

An imaginary straight line passing through the centres of curvature of lens is called **principal axis.**

Optical centre

The central point of a lens on principal axis is called an optical centre of lens. It is denoted as O.

Principal focus :

When rays parallel to the principal axis of convex lens are refracted through lens, they converge at a point on the principal axis. This point is called principal focus of a convex lens. A convex lens has two principal focii F_1 and F_2 on either side of lens.

The rays parallel to the principal axis of concave lens are refracted such that they appear to be diverging from a point on principal axis. Such point is called focus of concave lens. Concave lens also has two focii F_1 and F_2 on either side of lens.

Focal length (*f*) :

The distance between optical centre (O) and principal focus (F) is called focal length of a lens. It is denoted by *f*.

To locate the image formed by spherical lens, a ray diagram is constructed by considering any two of the following rays coming from the object point.

A ray of light from the object parallel to the principal axis of convex lens passes through the principal focus after refraction from convex lens on other side of lens (Figure 2.16 (a)).

In case of a concave lens, the ray appears to diverge from the principal focus located on the same side of lens as the object (Figure 2.16 (b)).

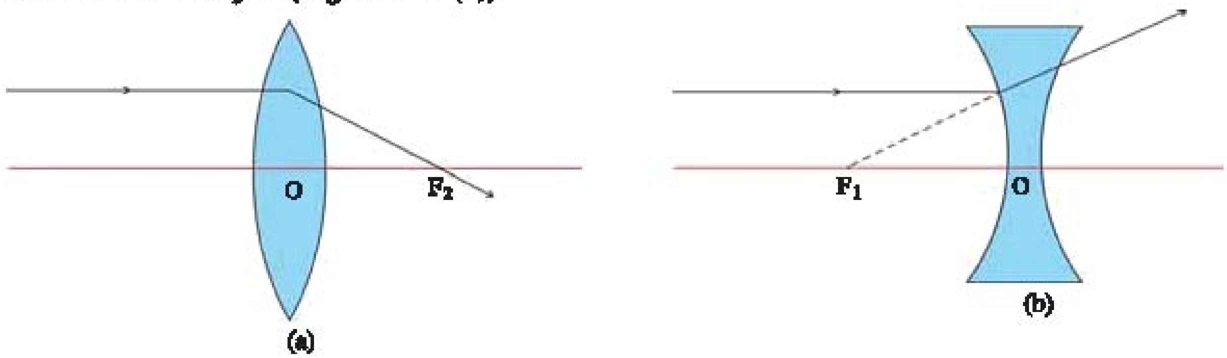


Fig. 2.16 Ray Incident Parallel to Principal Axis

A ray of light passing through a principal focus after refraction from a convex lens will emerge parallel to principal axis (Figure 2.17 (a)).

A ray of light moving toward the principal focus of a concave lens will emerge parallel to principal axis (Figure 2.17 (b)).

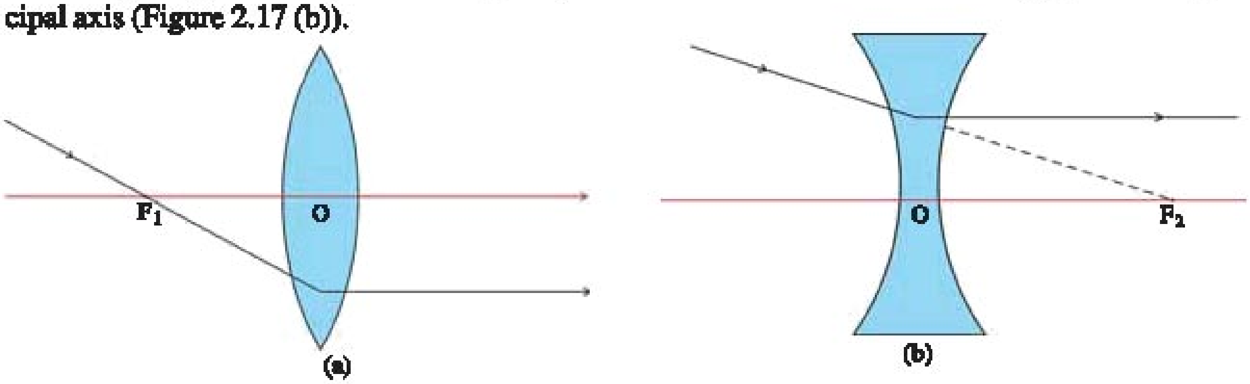


Fig. 2.17 (a) Ray passing through principal focus of convex lens

(b) Ray passing toward principal focus of concave lens

A ray of light passing through the optical centre (O) of convex or concave lens will emerge without any deviation. (Figure 2.18 (a) and 2.18 (b)).

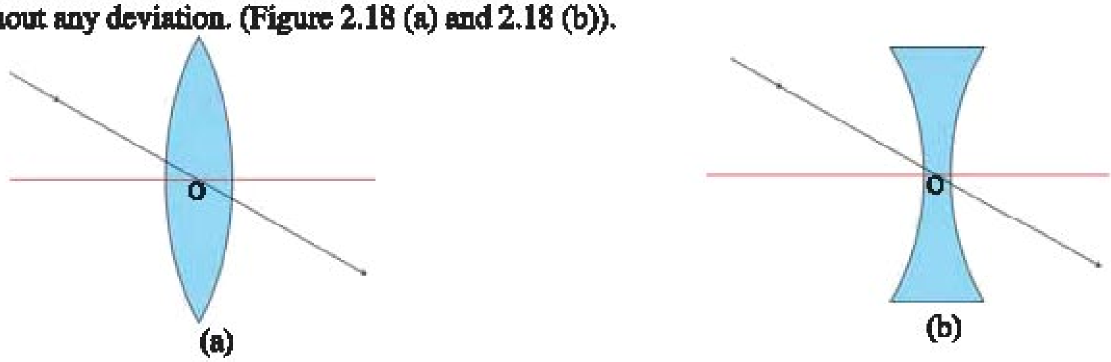


Fig. 2.18 Ray Passing Through the Optical Centre of Lens

Image Formation by Convex Lens

The table 2.5 shows the image formation by a convex lens for different situations of and extended object AB.

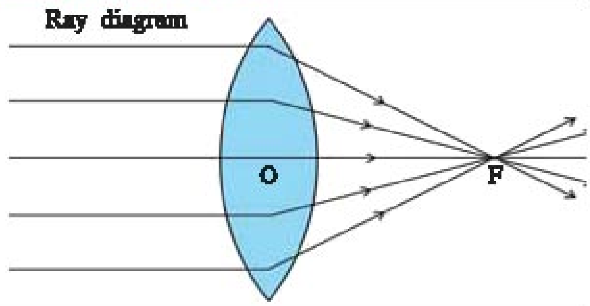
Table 2.5 Image Formation by Convex Lens

(1) Position of an object : At infinite distance

Position of image : On other side of lens at principal focus (F)

Nature : Real and inverted

Size : Highly diminished (point size)

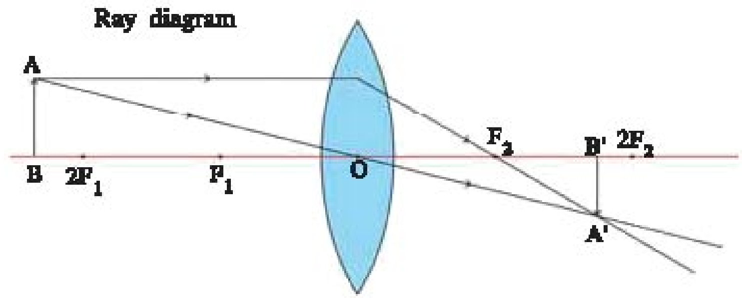


(2) Position of an object : Beyond the 2F

Position of image : On other side of lens between principal focus (F) and 2F

Nature : Real and inverted

Size : Smaller than object

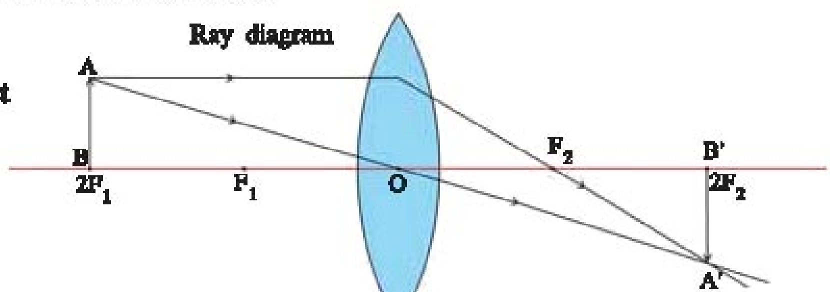


(3) Position of an object : At 2F

Position of an image : On other side of lens at 2F

Nature : Real and inverted

Size : Same size as the object

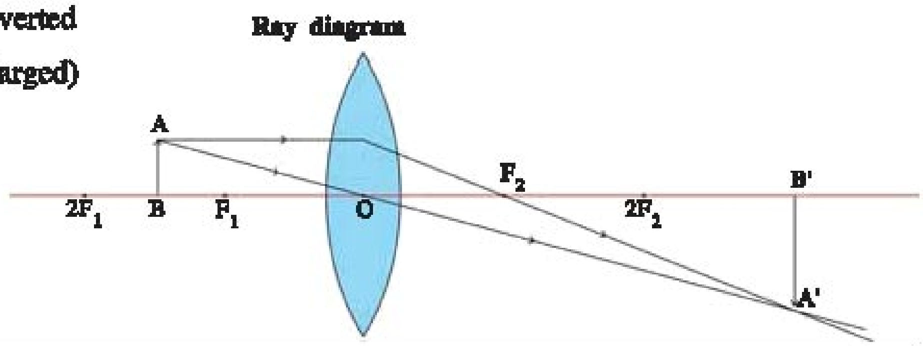


(4) Position of an object : Between principal focus (F) and 2F

Position of image : On other side of lens beyond 2F

Nature : Real and inverted

Size : Magnified (enlarged)

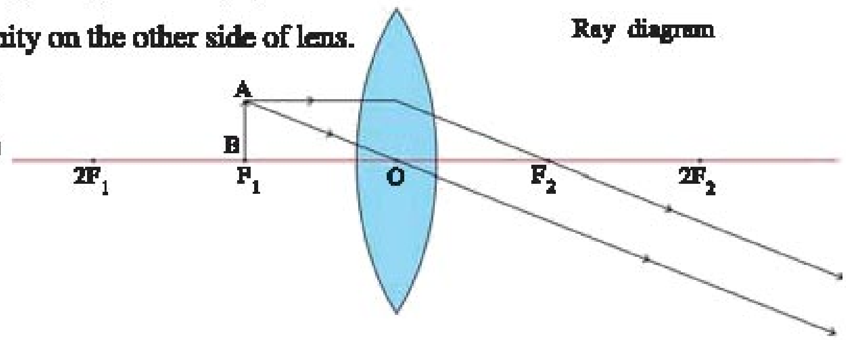


(5) **Position of object :** At the principal focus (F)

Position of image : At infinity on the other side of lens.

Nature : Real and inverted

Size : Magnified (enlarged)

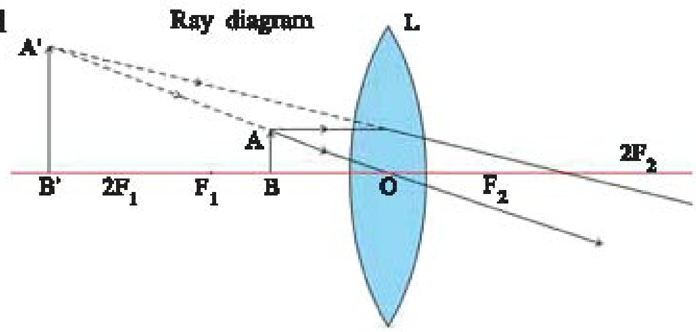


(6) **Position of object :** Between principal focus (F) and optical centre (O)

Position of image : On the same side of the lens as the object beyond 2F

Nature : Virtual and erect

Size : Magnified (enlarged)



Activity : 6

Hold a convex lens in your hand facing a distant object such as a pole. Move the lens back and forth gradually to get a sharp image of the distant object on the wall or screen. Measure the distance of screen from the lens using meter scale. The distance between screen and lens will give an approximate focal length of a convex lens. If you direct a convex lens towards the sun and get sharp bright spot on paper sheet, the paper starts buring with smoke. The bright spot on paper sheet is the real image of sun where the parallel rays from sun are concentrated and generates heat.

Image Formation by Concave Lens

The Table 2.6 shows the image formation by concave lens for the different positions of an extended object.

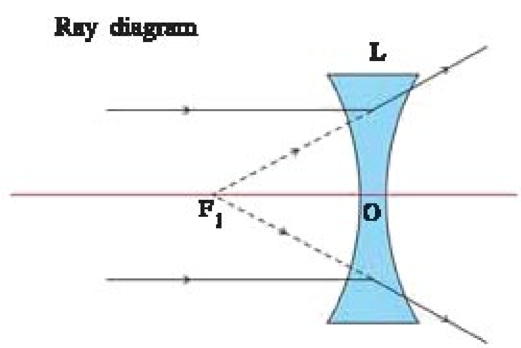
Table 2.6 Image Formation by Concave Lens

(1) **Position of object :** At an infinite distance

Position of image : On the same side of a lens as an object at principal focus F

Nature : Virtual and erect

Size : Highly diminished

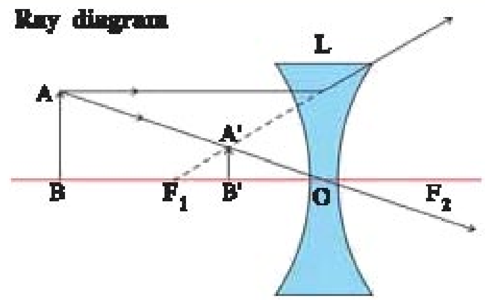


(2) **Position of object :** Between infinite point and optical centre (O).

Position of image : On the same side of lens as the object between focus (F) and optical centre (O).

Nature : Virtual and erect.

Size : Small (Diminished)



Activity : 7

Take a concave lens and place it on the lens stand. Keep a burning candle on one side of the lens, observe its image by looking from other side of lens. Try to obtain image on a screen if possible. Otherwise observe the image directly througth the lens. Note the position, nature and approximate size of the image. Now move the candle away from the lens and note the change in the size of an image.

What conclusion can you draw from the observations ?

A concave lens always forms virtual, erect and diminished image irrespective of the position of the object.

2.14 : Sign Convention for Spherical Lens

We follow the same sign conventions for spherical lenses as that used for spherical mirrors given in section 2.9. All the measurements are taken from the optical centre of the lens. For height of object and image also we use same sign convention as mirror. According to the sign convention, **the focal length of convex lens is positive and that of concave lens is negative.**

2.15 : Lens Formula and Magnification of Image

The equation which gives relation between object distance *(u)*, image distance *(v)* and focal length *(f)* is known as lens formula for a thin spherical lens of small aperture.

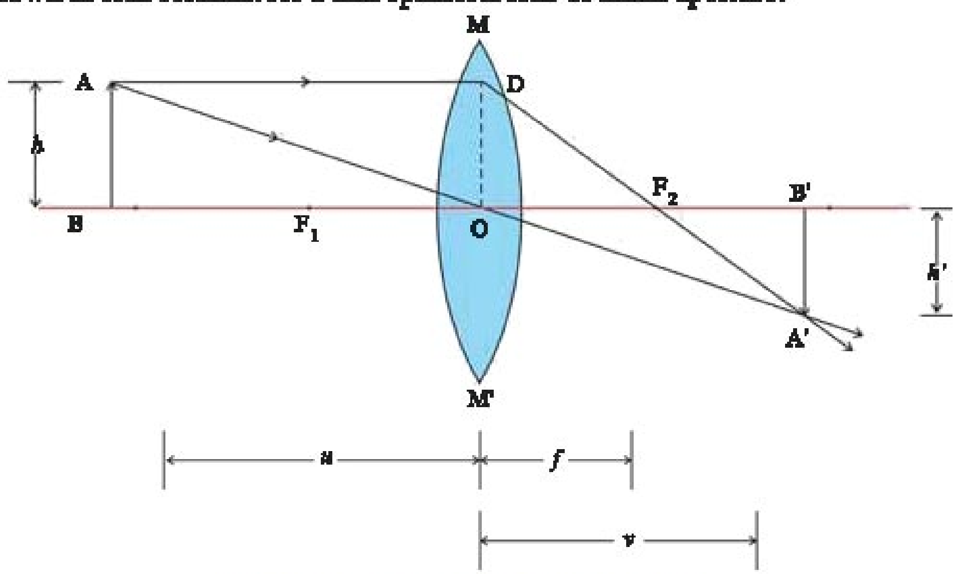


Fig. 2.19 Image formation by convex lens

As shown in Figure 2.19, object AB of height h is placd just beyond the centre of curvature at a distance *u* from the convex lens. Therefore, its real, inverted and diminished image B'A' will be formed at a distance *v* on the other side of the lens.

According to cartesian sign convention,

Object distance (OB) $= -u$

Image distance (OB_1) $= +v$

Focal length ($OF_1 = OF_2$) $= +f$

From Figure 2.19, right angled triangles Δ ABO and Δ A'B'O are similar.

$$\therefore \frac{AB}{A'B'} = \frac{OB}{OB'} = \frac{-u}{v} \qquad (2.15.1)$$

Similarly, right angled triangles Δ ODF_2 and Δ $B'A'F_2$ are similar.

$$\therefore \frac{OD}{A'B'} = \frac{OF_2}{F_2B'}$$

$$\therefore \frac{AB}{A'B'} = \frac{OF_2}{F_2B'}$$ (OD = AB as they are opposite sides of rectangle □ ABOD)

$$\therefore \frac{AB}{A'B'} = \frac{OF_2}{OB' - OF_2}$$

$$\therefore \frac{AB}{A'B'} = \frac{f}{v - f} \qquad (2.15.2)$$

From equations (2.15.1) and (2.15.2)

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

$$\therefore -u\,(v - f) = vf$$

$$\therefore -uv + uf = vf$$

Dividing each term by *uvf*,

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

$$\therefore \frac{1}{v} - \frac{1}{u} = \frac{1}{f} \qquad (2.15.3)$$

This equation (2.15.3) is known as **lens formula.**

Magnification of Image :

The magnification of an image formed by lens is defined as a ratio of height of image to the height of an object.

$$\therefore \text{ magnification} \quad m = \frac{\text{Image height}}{\text{Object height}} = \frac{h'}{h} \qquad (2.15.4)$$

In terms of object distance *(u)* and image distance *(v)*

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

$$AB = h \qquad A'B' = -h'$$

$\therefore$ From (2.15.4)

$$m = \frac{-h'}{h} \qquad (2.15.5)$$

$$\frac{v}{u} = \frac{-h'}{h} \qquad (2.15.5)$$

As u is negative and v is positive. So, magnification

$$m = \frac{v}{u} \qquad (2.15.6)$$

2.16 Power of Lens

The ability of a lens to converge or diverge light rays depends on its focal length. The convex lens of short focal length bends the light rays through large angles by focussing them closer to the optical centre. Similarly concave lens of very shorter focal length causes higher divergence than the one with larger focal length. The efficiency with which a lens converge or diverge the light rays is expressed in terms of its power.

The reciprocal of focal length of the lens is called a power of lens (p).

$$p = \frac{1}{f} \qquad \ldots (2.16.1)$$

The SI unit of power of lens is dioptre and is denoted by symbol D.

1D means the power of lens having 1m focal length.

Power of convex lens is positive and that of concave lens is negative. The optician prescribes corrective lens by indicatng their powers. The lens of power + 2.0 D represent the convex lens of focal length 0.5 m. The lens of power - 2.5 D represent the concave lens of focal length –0.4 m. The instrument used for measuring the power of lens is known as dioptremeter.

For Information Only

Many optical instruments consist of number of lenses. The combination of lenses increases magnification and sharpness of the image.

The resultant power (p) of lenses placed in contact is given by the algebraic sum of their individual powers p_1, p_2, p_3, ... as

$$p = p_1 + p_2 + p_3 + ...$$

The use of power instead of focal length of lenses is convenient for opticians. During the eye testing, an optician puts several different combinations of corrective lenses of known power as the total power is the simple algebraic addition. For example, combination of lenses of power + 2.0 D and + 0.25 D is equivalent to single lens of power + 2.25 D. The certain defect in the images produced by a simple lens can be minimised by combined lens system. Such systems are commonly used in the design of camera lenses and in the objective lenses of compound microscopes and telescopes.

Illustration : 6

A convex lens forms a real and inverted image of an object at a distance of 40 cm from it. What will be the distance of an object if size of an image is same as the object ? Determine the power of lens.

Solution :

As size of image = size of an object

$\therefore$ $m = -1$ for convex lens

$\therefore$ Object distance u = Image distance v

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

$u = -40$ cm

Substituting the value of u and v in formula of lens : $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

$$\frac{1}{40} + \frac{1}{40} = \frac{1}{f} \Rightarrow \frac{1}{20} = \frac{1}{f}$$

$\therefore$ Focal length of lens f = 20 cm = 0.2 m

$$\therefore \text{ Power of lens} = p = \frac{1}{f} = \frac{1}{0.2} = +5.0\,\text{D}$$

Illustration : 7

A concave lens has a focal length of 20 cm. At what distance should the object from the lens be placed a so that it forms the image at a distance 10 cm from the lens ?

Solution : Image fromed by concave lens is virtual, erect and on the same side of a lens as an object.

Image distance $v = -10$ cm

Focal length $f = -20$ cm

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

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

$$\therefore \frac{1}{u} = \frac{-1}{10} + \frac{1}{20}$$

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

$$\therefore u = -20 \text{ cm}$$

∴ The object should be 20 cm from concave lens on left.

Illustration : 8

The object of 5 cm height is placed at a distance 25 cm from the centre of convex lens of focal length 10 cm. Draw a ray diagram and find position, nature and the size of an image formed.

Solution :

Take a scale 2.5 cm = 1 unit on principal axis and draw a ray diagram. The ray diagram will be number 2 of Table 2.5.

This shows that real, inverted and diminished image of an object is formed on other side of lens at a distance of 8.3 cm from the lens.

2.17 Optical Instruments

On the basis of images formed by convex lenses by keeping the object at different positions, we shall discuss some optical instruments as under :

(1) Simple Microscope

When an object is placed between optical centre and focus of a convex lens, its virtual, erect and magnified image behind the object, is obtained. Simple microscope works on this principle.

A convex lens used for obtaining magnified image of the object is known as a simple microscope.

(2) Compound Microscope

The simple microscope cannot form clear magnified image beyound certain limit. The compound microscope having two lenses can form the magnified image of the object with better clarity. The ray diagram for the compound microscope is shown in Figure 2.20.

The lens towards the object is called objective lens and the lens near the eye is called eye piece. The focal length of objective lens is small compared to the eye piece.

Working :

The object AB to be observed is placed at a distance slightly more than focal length (f_o) of objective lens so that its real, inverted and magnified image A'B' is obtained beyond the centre of curvature (C) of objective lens. The image A'B' becomes an object for the eye piece. The position of an image A'B' is adjusted such that it will be within the focal length (f_e) of eye piece. The eye piece forms virtual, erect and magnified image A"B" of the object.

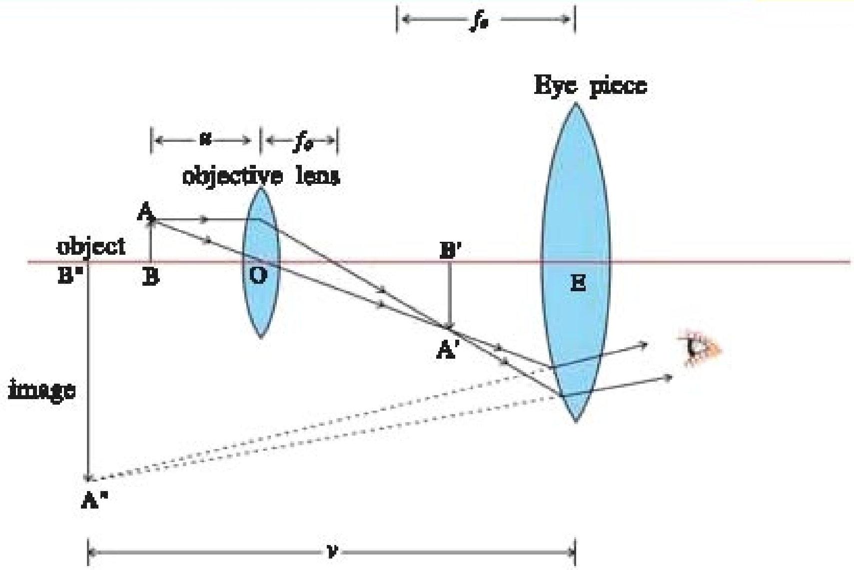


Fig. 2.20 Ray Diagram of compound Microscope

Thus, the final image formed by compound microscope is virtual, inverted and magnified behind the object.

(3) Astronomical Telescope

The far distant objects such as planets, stars and moon etc. appear very small and close to each other. They can be observed by astronomical telescope.

The ray diagram for astronomical telescope is shown by Figure 2.21.

Construction : Astronomical telescope has co-axial arrangement of two convex lenses. Lens towards the object is called objective lens and the convex lens near the eye is called the eye piece.

The focal length of objective lens (f_o) is large as compared to the eye-piece.

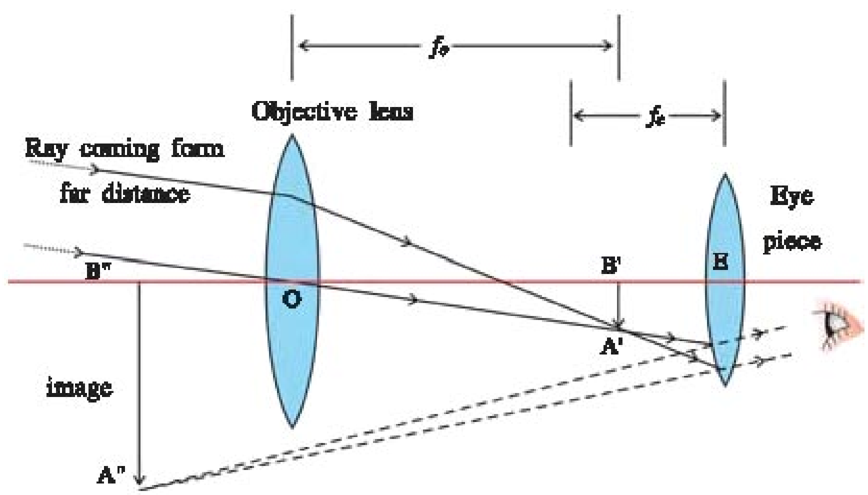


Fig. 2.21 Ray Diagram of Astronomical Telescope

Working :

When telescope is focussed on a distant object, parallel rays coming from the object form real, inverted and diminished image A'B'. This image acts as an object for eye piece arranged in such a way that its virtual, magnified and erect image A"B" will be formed.

Thus final image of object is virtual, inverted and diminished.

For Information Only

Telescope used for the observation of distant object on earth is known as terrestrial telescope. One more convex lens is introduced between objective lens and eye piece so that the final image of an object is erect. The astronomical telescope forms inverted image of the object.

Hubble telescope was launched into orbit around earth in 1990 to obtain the information about universe in the visible, infrared and ultraviolet region of an electromagnetic spectrum. It is named after the well known American astronomer Sir Edwin Powell Hubble (1889-1953).

The various centres for Astronomy and Astrophysics in India use Radio Telescopes for their research programmes. Giant Meterwave Radio Telescope (GMRT) world's largest array of radio telescope, is situated at Narayangaon, 80 km from Pune, India. It is an institute of international acclaim, where astronomers from all over the world visit and use GMRT to observe many astronomical objects such as Galaxies, Pulsars and Supernovae. GMRT is a unique facility provided by National Centre for Radio Astronomy (NCRA), a branch of Tata Institute of Fundamental Research (TIFR), Bombay.

Some other well known centres in India are at Ooty (Tamilnadu) Gauribidnaur (Karnataka), Girishikhar, Mount Abu (Rajasthan), Kodaikanal (Tamilnadu) that offer facilities of radio telescope.

What have you learnt ?

- Light is an electromagnetic wave which produces sensation in our eyes.
- Light travels with the speed of 3×10^8 m s^{-1} in vacuum.
- A straight line path joining one point to another in the direction of propagation of light is called a ray and a bundle of such rays is known as a beam of light.
- A mirror can focus the beam of light through reflection whereas a lens can focus the beam of light through refraction.

- In regular reflection, a beam remains parallel after reflection whereas in irregular reflection beam spreads over wide area after reflection.
- The images formed by plane mirror is always virtual and erect.
- The phenomenon due to which the right side of an object appears as left and left side of an object appears right is called lateral inversion.
- A concave mirror has inward reflecting surface and convex mirror has outward reflecting surface.
- The concave mirror forms real as well as virtual image. The convex always forms virtual and erect image.
- Focal length is positive for convex mirror and convex lens.
- Focal length is negative for concave mirror and concave lens.
- The distance of an object is always negative while its height is always positive.
- Radius of curvature = 2 × focal length.
- Mirror formula : $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$ Lens formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$
- Rules for ray diagram to locate the image formed by concave mirror :
  (i) A ray of light parallel to the principal axis, after reflection passes through the principal axis.
  (ii) A ray of light passing through the principal axis of a mirror, gets parallel to the principal axis after reflection.
  (iii) A ray of light passing through the centre of curvature of mirror is reflected along the same path.
  (iv) A ray of light incident obliquely towards the pole of mirror reflects obliquely as per the laws of reflection.
- The ratio of the height of image to the height of the object is called the magnification of an image.
- Magnification is positive for virtual image and negative for real image.

  Magnification for mirror : $m = -\frac{v}{u}$ Magnification for lens : $m = \frac{v}{u}$
- The phenomenon of change in velocity of light from one transparent medium to another is called refraction of light..
- The angle formed between the incident ray and the normal at the point of incidence is called angle of incidence.
- The angle formed by refracted ray with the normal at the point of incidence is called angle of refraction.
- When a ray of light passes from a rarer medium to denser medium, it moves towards the normal.

- When a ray of light passes from a denser medium to rarer medium, it moves away from the normal.
- Snell's law of refraction :

$$n = \frac{\sin\ i}{\sin\ r}$$

- The ratio of speed of light in vacuum to the speed of light in a medium is called the absolute refractive index of the medium.
- The shift of emergent ray side ways from the direction of incident ray is called lateral shift.
- The extent of lateral shift depends upon angle of incidence, refractive index of medium and the distance between two parallel refracting surfaces.
- The optically denser medium has larger absolute refractive index compared to optically medium rarer.
- The convex lens converges the ray of light whereas cancave lens diverges a ray.
- Power of lens is the reciprocal of its focal length. Its SI unit is Dioptre.
- **Nature, size and position of images formed by concave mirror :**

Position of Object	Position of Image	Nature of Image	Size
(1) At infinity	At focus F	Real and inverted	Highly diminished
(2) Beyond C	Between C and F	Real and inverted	Diminished
(3) At centre of curvature C	At centre of C	Real and inverted	Same as object
(4) Between C and F	Beyond C	Real and inverted	magnified
(5) At focus F	At infinity	Real and inverted	highly magnified
(6) Between pole P and focus F	Behind mirror	Virtual and erect	magnified

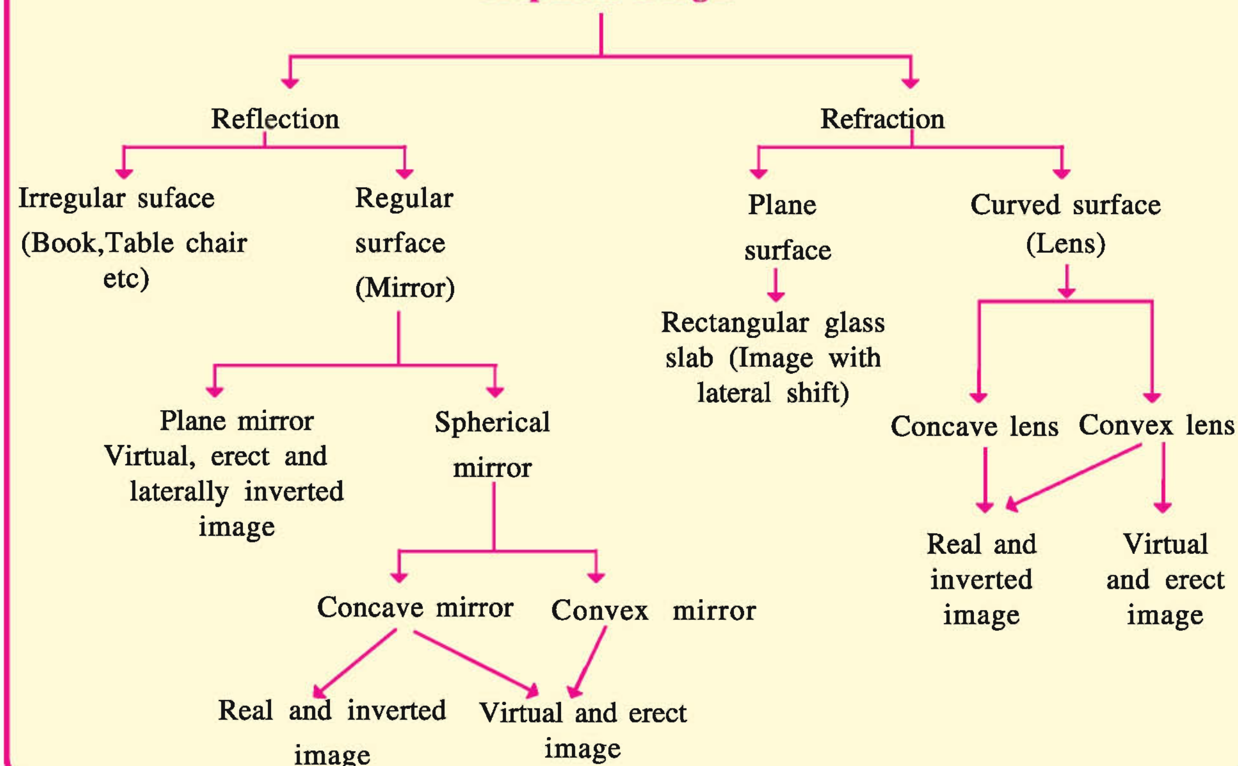
- Position, nature and size of image formed by convex mirror

Position of Object	Position of image	Nature of image	Size
(1) At infinity	At focus F behind mirror	Virtual and erect	Highly diminished (point sized)
(2) Between infinity and pole	Between pole P and Focus F behind mirror	Virtual and erect	Diminished

- When image formed by convex lens is real, its position, nature and relative size are same as that by the concave mirror. In concave mirror, the image is formed on the same side of object whereas in convex lens it is on another side of an object. The optical centre (O) in the convex lens plays role of pole (P) that is in concave mirror. The images formed by concave mirror and convex lens for an object placed at a distance less than focal length show different characteristic.

- The nature and relative size of an image formed by convex mirror and concave lens are same. The position of an image formed by concave lens is on the same side as the object while for convex mirror it is behind the mirror.
- When a convex lens is used for obtaining the magnified image of an object, it is called simple microscrope.
- The focal length of objective lens is smaller compared to that of eye piece in a compound microscope.
- The objective lens has larger focal length compared to that of eye piece in astronomical telescope.

Properties of Light



EXERCISE

1. Select the proper choice from the given multiple choices :

(1) What is the wavelength range of visible light ?

(A) 4×10^{-7}m to 8×10^{-7}m (B) 4×10^{-9}m to 8×10^{-9}m

(C) 4×10^{-5}m to 8×10^{-5}m (D) 4×10^{-6}m to 8×10^{-6}m

(2) What is the relation between radius of curvature (R) and the focal length (f) of a spherical mirror ?

(A) $R = f/2$ (B) $R = f$ (C) $R = 2f$ (D) $R = 3f$

(3) Which type of reflection will be represented by a light reflected from a book ?

(A) Regular (B) Irregular (C) Both types (D) None

(4) Through which of the following points, a ray passing through a centre of curvature and reflected by concave mirror will pass through ?

(A) Focus (B) Centre of curvature

(C) Pole (D) All

(5) At what distance in front of the concave mirror should an object be placed to get its virtual and erect image ?

(A) At centre of curvature (B) Beyond centre of curvature

(C) Between focus and pole (D) At focus

(6) The magnification of plane mirror is always ....

(A) More than 1 (B) 1

(C) Less than 1 (D) Zero

(7) The focal length of plane mirror is ....

(A) Zero (B) Infinity

(C) Uncertain (D) Equal to object distance.

(8) The distance between the object at 2 m from a plane mirror and its image is ....

(A) 4 m (B) 1 m (C) 2 m (D) 3 m

(9) At what distance should an object be placed to obtain its real, inverted and of same height as the object by a convex lens ?

(A) At focus (B) Between focus and centre of curvature

(C) At centre of curvature (D) Between optical centre and focus.

(10) Which of the following materials has maximum optical density ?

(A) Glass (B) Water (C) Pearl (D) Diamond

(11) The absolute refractive index of any medium is always......

(A) 1 (B) > 1 (C) < 1 (D) Zero

(12) Which of the lenses with focal length 10 cm, 20 cm, 25 cm, and 50 cm has maximum power ?

(A) 50 cm (B) 25 cm (C) 20 cm (D) 10 cm

(13) What is the focal length of a convex lens having power + 5.0 D ?

(A) – 10 cm (B) – 20 cm (C) + 10 cm (D) + 20 cm

(14) If the absolute refractive indices of water, benzene, and saphire are 1.33,1.50 and 1.77 respectively, then which medium has maximum relative refractive index ?

(A) Saphire relative to water (B) Saphire relative to benzene

(C) Benzene relative to water (D) Water relative to benzenes

(15) Which type of an image is formed by a plane mirror ?

(A) Real and inverted (B) Real and erect

(C) Virtual and erect (D) Virtual and inverted

(16) If the absolute refractive indices of water and glass are 4/3 and 3/2 respectively, then what will be the ratio of velocity of light in water to that of glass ?

(A) 2 (B) 8/9 (C) 9/8 (D) 1/2

(17) The absolute refractive indices of water glass and diamond are 1.77, 1.50 and 2.72 respectively, which medium is most optically denser ?

(A) Water (B) Glass (C) Diamond (D) None

(18) Which of the following always form virtual image ?

(A) Concave mirror and convex lens (B) Convex mirror and concave lens

(C) Convex mirror and convex lens (D) Concave mirror and concave lens

(19) What will be the angle of refraction for the light ray incident normal at the surface ?

(A) 90^0 (B) 60^0 (C) 30^0 (D) 0^0

(20) The compound mirroscope consists of two convex lenses of 5 cm and 20 cm focal length, then which of them will be object lens and eye piece ?

(A) Object lens with 20 cm focal length and eye piece with 5 cm focal length.
(B) Object lens with 5 cm focal leugth and eye piece with 20 cm focal length.
(C) Both should have 20 cm focal length.
(D) Both should have 5 cm focal length.

2. Answer the following questions in brief :

(1) What is called regular and irregular reflection of light ?

(2) Write the laws of reflection of light.

(3) What are called centre of curvature and radius of curvature of mirror ?

(4) Draw a ray diagram showing position, nature and size of an image formed by concave mirror when the object is placed beyond the centre of curvature.

(5) Draw a ray-diagram showing position, nature and size of an image formed by concave mirror when the object is placed between pole and principal focus.

(6) Draw a ray-diagram showing position, nature and size of an image formed by convex mirror when the object is placed between infinite distance and pole.

(7) Obtain the position, nature and size of an image formed by a plane mirror from the formula of magnification.

(8) Write laws of refraction of light.

(9) What is called the absolute refractive index of a medium ? Obtain the general form of Snell's law in terms of refractive indices of two media ?

(10) Draw a ray-diagram showing the position, nature and size of an image formed by convex lens when the object is placed at centre of curvature of lens.

(11) Draw a ray-diagram showing the position, nature and size of an image formed by a convex lens when object is placed between its optical centre and focus.

(12) Draw a ray-diagram showing the position, nature and size of an image formed by a concave lens when the object is placed between an optical centre and infinite point.

(13) What is called the magnification of an image ? Derive the formula of magnification for spherical lens.

3. Write answers of the following questions :

(1) Explain the reflection by a plane mirror by drawing suitable figure.

(2) Give the cartesian sign convention for the reflection by spherical mirror.

(3) With the necessary figure, explain the refraction of light through a rectangular glass slab.

(4) Obtain the lens formula for spherical lens.

(5) Explain how the position of an image is located for spherical mirror by considering the different rays using necessary ray-diagrams.

(6) Write a note on power of lens.

4. Answer the following questions in detail :

(1) Derive the formula for spherical mirror

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

(2) Explain the construction and working of a compound microscope with a neat ray-diagram.

(3) Write a note on astronomical telescope.

5. Solve the following problems :

(1) An object of height 5 cm is placed at a distance of 10 cm from convex mirror of focal length 15 cm. Find the position, nature and size of an image.

(**Ans :** Virtual, erect and diminished image at a distance 6 cm behind the mirror. Height of image = 3 cm)

(2) An object of height 6 cm is placed at a distance of 15 cm from a concave mirror of focal length 10 cm. Find position, nature and height of an image.

(**Ans :** $v = -30$ cm, height = 12 cm, Real, inverted and magnified)

(3) The rays of light are entering from glass into glycerine. If the absolute refractive indices of glass and glycerine are 1.5 and 1.47 respectively, find the refracting index of glycerine relative to glass. (**Ans :** 0.98)

(4) The refractive index of light entering glass from water is 1.12. Find absolute refractive index of water if the absoute refractive index of glass is 1.5.

(**Ans :** 1.34)

(5) When the light entering from glass to water, refractive index of water with respect to glass is 0.9. The angle of incidence at the surface seprating two media is 26°48'. Find the angle of refraction at the surface.

Take sin 26°48' = 0.45 approximately.

(**Ans :** Angle of incidence = 30°)

(6) An object is placed perpendicular to the principal axis of a convex lens having focal length 10 cm. The distance of an object from the lens is 15 cm. Find the position of an image.

(**Ans :** v = 30 cm)

(7) An object is placed perpendicular to the principal axis of concave lens of focal length 30 cm. Find the position of an image when the object is at a distance 20 cm from the lens.

(**Ans :** v = – 12 cm)

(8) A power of convex lens is + 4.0 D. At what distance should the object from the lens be placed to obtain its real and inverted image of the same size on the screen ?

(**Ans :** u = 50 cm. At the centre of curvature of lens)

UNIT

3

DISPERSION OF LIGHT AND NATURAL OPTICAL PHENOMENA

3.1 Introduction

Dear student,

In Chapter 2, you have studied about reflection and refraction of light. In addition to that position, nature and size of the image formed by mirrors and lenses were also discussed. You have also obtained the understanding about the formation of the image in Compound Microscope and Astronomical Telescope using convex lens. This technique is very helpful in understanding the functioning of lens in human eye. The lens also plays an important role correcting the defect of vision in human eye. The reflection and refraction of light are very useful in explaining natural phenomena like the formation of rainbow, twinkling of stars and mirage formation. In this chapter you are going to study some natural phenomena based on refraction, dispersion and the scattering of light.

3.2 Dispersion of White Light Through a Glass Prism

In the monsoon season the phenomenon of rainbow indicates the fact that "White light is composed of seven colours". To understand the dispersion of white light into seven colours consider the following activity.

Activity : 1

- Take a glass prism.
- Incident the sunlight on one of the face of prism through a narrow slit.
- Turn the prism slowly until the light is emerged from the prism and capture on the screen.
- What do you obsevre ?

You will get beautiful bands of different colours on screen. The prism splits incident white light into seven colours in the sequence, " Violet, Indigo, Blue, Green, Yellow, Orange and Red." as seen from Figure 3.1. The acornym "VIBGYOR" is useful to remember the sequence of colours.

The phenomenon of splitting of white light into its constituent colours is called dispersion of light.

The band of seven colours obtained from the splitting of white light is called spectrum.

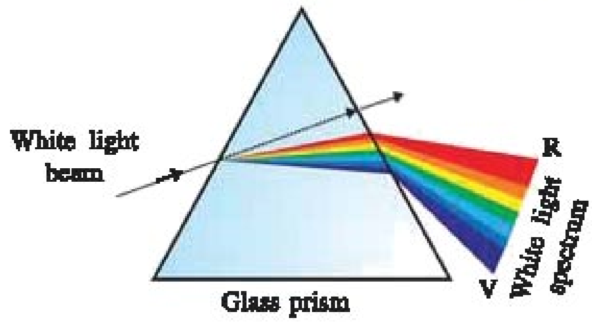


Fig. 3.1 Dispersion of white light by the glass prism.

All the constituent colours of a white light have same velocity in vacuum. When it passes through a transparent medium like glass, water, glycerin etc., their velocity changes and due to that deviation of the different constituent colours occur at different angles. In a transparent medium, violet coloured light is deviated maximum and the red coloured light is deviated minimum because in a medium, the velocity of violet coloured light is minimum and that of red coloured light is maximum (figure 3.1). Thus, the dispersion of white light occurs due to the refraction of constituent colours at different angles. In similar way the white light is obtained by recombination of these seven constituent colours. This is explained by the following activity :

Activity : 2

- Take two prisms P_1 and P_2 of same prism angles.
- Arrange them as shown in Figure 3.2.
- Now allow a narrow beam of white light to incident on one face of prism P_1.
- Observe the beam of light emerging from pirsm P_2 on nearby screen or wall.
- Show your observation.

As shown in Figure 3.2, the first prism P_1 disperses the white light into seven constituent colours. The second prism P_2 recombines these seven colours into a beam of white light. Therefore, a white light is again observed on the screen.

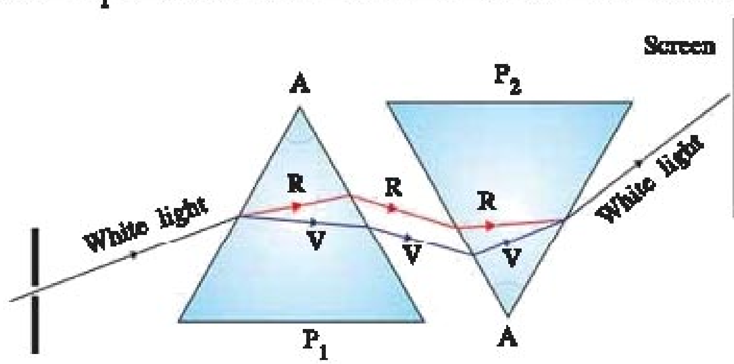


Fig. 3.2 Recombination of spectrum of white light

From this experiment, Newton established that a white light is composed of seven constituent colours. Thus, the structure of white light can be understood through the phenomenon of dispersion of light.

3.3 Primary Concept of Colours of Objects

The colour sensed by our eyes depends upon the colour of rays entering into our eyes. Out of the spectrum of white light obtained by a prism as a band of seven colours, green colour of leaf and red colour of rose entering our eyes are its known examples.

To explain why the objects are seen colourful, consider the following activity.

Activity : 3

- Take a torch that produces white light.
- Take blue, green and red coloured plates or transparent papers.
- Obtain green coloured light by passing a white light through green plate. Incident this light on green coloured object (e.g. green leaf) which will appear green coloured.
- Now obtain blue and red coloured light in the similar way and incident them on the same green coloured object which will appear black coloured.
- Now observe the red coloured object under blue and green coloured light and the blue coloured object under red and green coloured light which will also appear black coloured.

When the light is incident on the object, the absorption of some colours and reflection of some colours from the object takes place. The colour of light which is reflected from the object determines the colour of an object. When the white light is incident on green leaf, all the colours except green colur are absorbed and the green colour is reflected, so the leaf appears green coloured. Due to the same reason, the red colour of rose is to be seen.

Now when green coloured light is incident on red coloured rose, it will be absorbed and no light will be reflected from it, hence it appears black.

When the object appears black coloured, there will be no reflection of any constituent colour of light.

When all the constituent colours are reflected from the object, it appears white.

Primary colours of light and their superposition :

In the dispersion of white light, we have seen that the white light has seven constituent colours and from the recombination of these colours white light is obtained.

However, it is not necessary to combine all these constituent colours to obtain white light. The combination of only red, blue and green in proportion also gives white light.

Thus red, blue and green colours are said to be primary colours of white light.

The method of producing a wide range of colours by the appropriate mixture of these primary colours is known as an **additive mixture method.** The colours obtained by the mixture of primary colours in this way are known as **composite colours**.

Consider the following activity to know how the composite colours are obtained :

Activity : 4

- Take three torches and transparent glass plates of red, blue and green colours and obtain light of these three colours.
- Now place a white paper on a table. Arrange these three torches horizontally on a table in such a way that the patches of all three colours are seen (Figure 3.3).

You will observe that,

- The portion of the white paper where all the three patches superimpose on one another will appear white.
- The portion of the screen where blue and green light superimpose appears cyan.
- The portion where blue and red colour superimpose appear magenta and it will be yellow at the superposition of red and green colour.

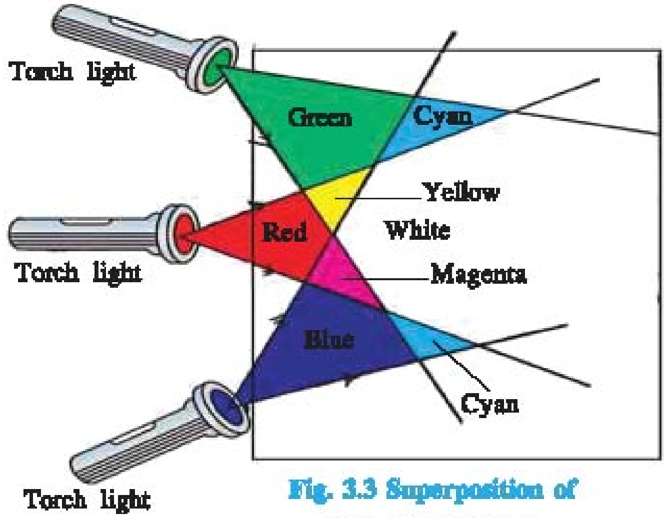


Fig. 3.3 Superposition of primary colours

Thus, combining primary colours as shown in Figure 3.4 and Table 3.1 shades of different colours are obtained.

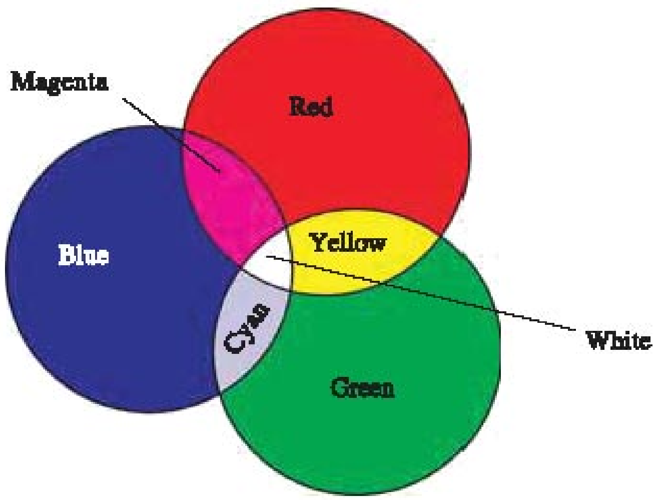


Fig. 3.4 Mixing of primary colous of light

Table 3.1 Superposition of primary and composite colours

Number	Colours for mixing	Resultant colour
1.	Blue, Red	Magenta
2.	Blue, Green	Cyan
3.	Red, Green	Yellow
4.	Blue, Green, Red	White
5.	Blue, Yellow	White
6.	Green, Magenta	White
7.	Red, Cyan	White

Any two colours, which on mixing, produces a light of white colour are called complementary colours.

From Table 3.1, blue and yellow, green and magenta, red and cyan are complementary colours.

Note that mixing of primary colours of light in various proportion gives the entire spectrum of colours. This technique is used to obtain colourful picture in a colour television, computer etc.

Colours and pigments :

The coloured substances which are used as a paint are known as pigments. The paints used for drawing and painting the infrastructures are well known examples of pigments.

The cyan, magneta and yellow are the primary pigments.

Just as the white light is obtained by mixing the primary colours of light using additive method, the white pigment cannot be obtained on mixing the primary pigments. In order to obtain the various pigments, the **substractive method** is used for mixing the pigments.

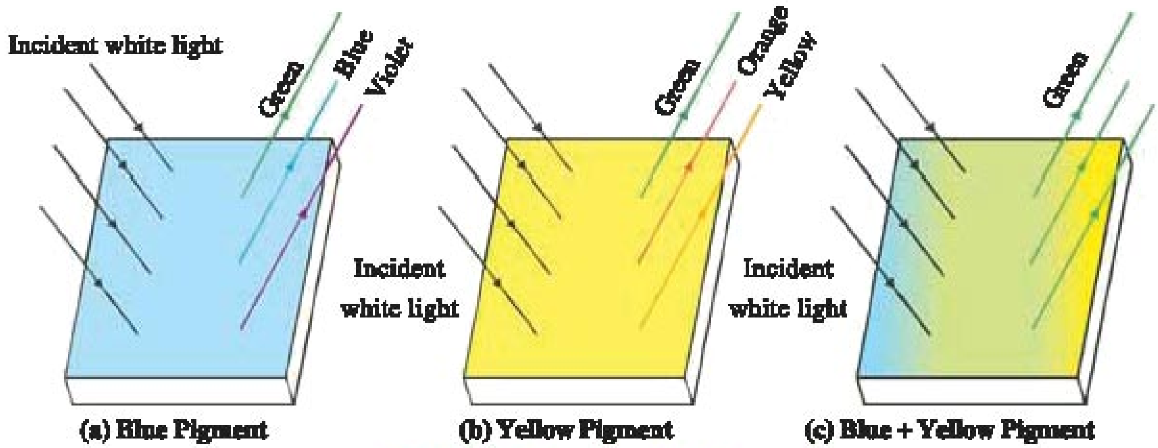


Fig. 3.5 : Reflection of light from pigments

As shown in Figure 3.5 (a), when the white light is incident on blue pigment blue, violet and green colours are reflected and the remaining colours are absorbed. If the white light is incident on yellow pigment, only yellow, green and orange colours are reflected (Figure 3.5 (b)). Thus, the green colour of light is not absorbed by yellow and blue pigment. Therefore, if blue and yellow pigments are mixed, then they will reflect only green coloured light (Figure 3.5 (c)).

Thus, by substractive mixture method, various pigments are obtained.

3.4 Human eye

The human eye is the best natural optical instrument whose construction can be compared with that of the camera. We can view the wonderful world around us through the eyes.

A simple sketch of human eye along with the labelling of its main parts is shown in the Figure 3.6.

The light rays coming from the object first enter the eye through cornea. A muscular diaphragm behind the cornea is known as an iris which can control the amount of light that enters into the eye. An aperture of an eye behind the cornea at the center is known as pupil whose size can be controlled by Iris. After passing through the pupil, the light rays are incident on a jelly like elastic material known as an eye-lens. The muscular structures which hold the eye-lens in its position are known as ciliary muscles. They change the focal length of an eye-lens by changing its thickness. Position of image where image formed due to refraction by eye-lens is called retina. When the light rays fall on retina, the light sensitive cells generate electrical signals. The signals are sent to the brain through the optic nerves where the image of an object is interpreted.

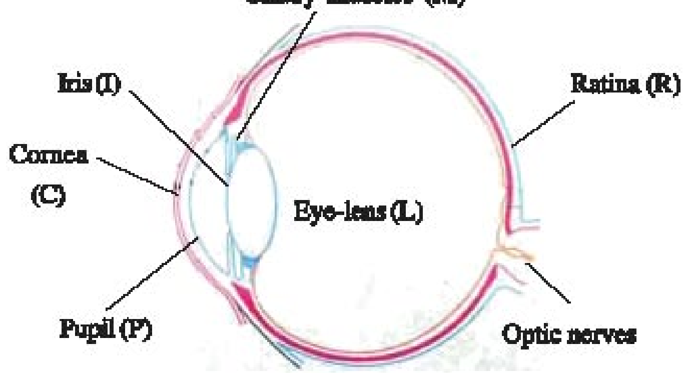


Fig. 3.6 Construction of human eye

Accommodation power of an eye :

The ciliary muscles can modify the curvature of lens of human eye up to certain extent only. The focal length of lens changes with the change in the curvature of an eye-lens. In the normal situation of ciliary muscles, the lens is thin and its focal length is more. This enables eye to see the distinct oject clearly. When the ciliary muscles contract, the focal length is decreased due to the increase in the curvature of an eye lens and an eye will be able to see nearby object clearly.

The ability of an eye-lens to adjust its focal length as per requirement is called accommodation power of an eye.

The minimum distance at which the object can be seen clearly without contraction of eye-lens is called the least distance of distinct vision. This distance is also called **near point of an eye**. For young adult with normal vision the value is 25 cm.

The farthest distance upto which the eye can see objects clearly is called **far point of an eye**. It is infinite for the person having normal vision.

Thus, a person with normal vision can see object clearly from 25 cm to infinite distance.

Defects of vision and its remedies :

You know that the light rays coming from the object forms the image on retina after being refracted by an eyelens. To see the clear image of an object, its image should be formed exactly on retina. When cilliary muscles cannot change the thickness of eye-lens as per requirement, the defect of vision arise.

Generally, three main types of common defects of vision arise in eye :

(i) Near-sightedness or Myopia. (ii) Far-sightedness or Hypermetropia. (ii) Presbyopia

(i) Near-sightedness : If eye-lens does not become thin as per requirement, the light rays from distinct object are focussed at the distance shorter than retina after being refracted from eye-lens. So the distant object cannot be seen clearly, this type of defect is called **near-sightedness or myopia** (Figure 3.7). Though nearby object may be seen clearly. This defect can be corrected by using a concave lens of suitable power as shown in Figure 3.8.

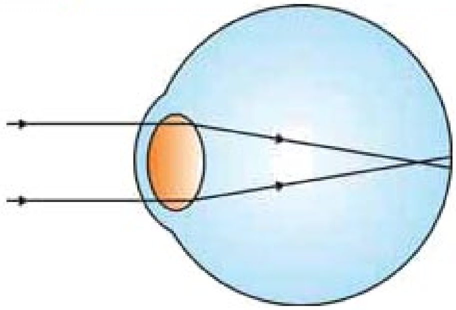


Fig. 3.7 Defect of near-sightedness

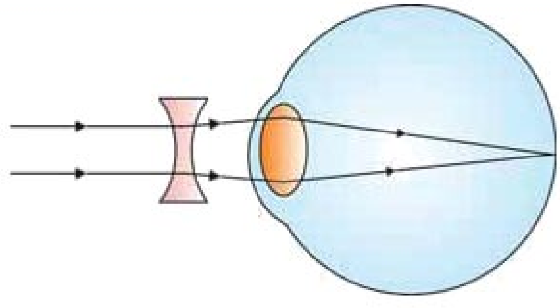


Fig. 3.8 Correction (Remedy) of near-sightedness using concave lens

(ii) Far-sightedness or Hypermetropia : If the eyelens does not become thick as per requirement, the rays coming from nearby object will be focussed beyond the retina. Thus nearby object cannot be seen clearly, this type of defect of an eye is known as **far-sightedness or hypermetropia** (Figure 3.9). Though the distant object may be seen clearly. This defect can be corrected by using a convex lens of appropriate power (Figure 3.10).

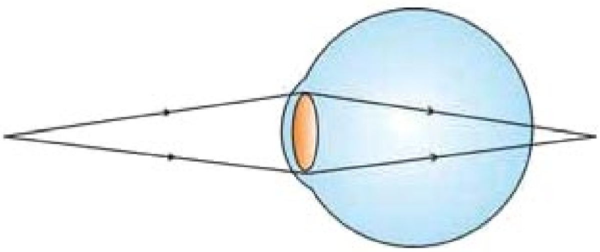


Fig. 3.9 Defect of far-sightedness

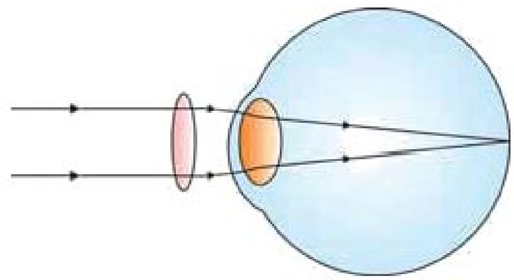


Fig. 3.10 Correction of far-sightedness using convex lens

(iii) Presbyopia : The power of accommodation of an eye usually decreases with ageing. The near point of aged persons recedes and they find it difficult to see nearby objects clearly without spectacles. Moreover, some times they also find difficult to see a distant object without spectacles. This defect of an eye arises due to weakening of cilliary muscles and loss of elasticity of eyelens. This defect is called presbyopia. For the remedy of this defect, spectacles of bifocal lens are used. Generally upper part bifocal lens is made up of concave lens and a lower part of a small circular section is made up of convex lens.

In present times, contact lens and laser surgery are widely used to remove the defect of eyes.

When a milky and cloudy layer is formed on the eye lens of old age persons, they loose their vision partially or completely. This type of situation is called **cataract**. It can be removed by surgery.

3.5 Formation of Rainbow

A rainbow is a natural spectrum visible in the sky after rainshower. It is caused by the dispersion of sunlight by tiny water droplets present in the atmosphere. A rainbow is always formed in the direction opposite to that of sun. The water droplets act like small prisms. They disperse the incident light first, then reflect it internally (not necessarily total internal refleciton) and finally refract it again while it comes out of rain drop as shown in the following Figure 3.11.

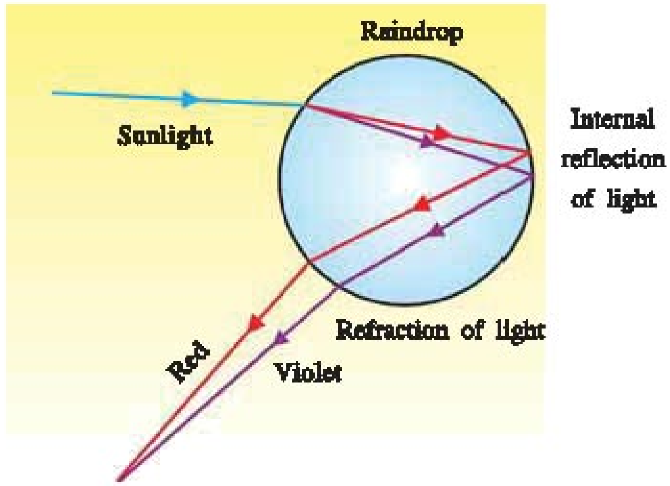


Fig. 3.11 Formation of rainbow

The different colours of light enter into our eye due to the dispersion and internal reflection of light. Looking from lower to higher order colours form violet toward red arc is known as **primary rainbow.**

Some times you may have seen two rainbows in the sky out of which the order of colours in upper rainbow is reverse to the primary rainbow is called **secondary rainbow.**

You may also see a rainbow on a sunny day when you look at a water fall with the sun behind you.

3.6 Atmospheric refraction

The density of earth's atmosphere is non-uniform everywhere as it consists of layers of different densities. The layer at lower altitude from the earth has more density than that at the higher altitude. As a result of this, the refractive index of atmosphere decreases continuously from lower to higher altitude. Here, the physical situations of refracting medium (atmospheric air) are also not steady, so the apparent position of the object also fluctuates. This phenomenon is known as an atmospheric refraction or the refraction of light by earth's atmosphere.

The phenomena like twinkling of stars, early sunrise and delayed sunset occur due to this effect.

Twinkling of Stars :

As the stars are very far, they may be considered to be point sources of light. When star light passes the atmosphere, it bends continuously towards the normal till it enters our eye due to the refraction so that its apparent position is slightly higher than its actual position. Due to the mobility of an air and changes in temperature, the refractive index of atmosphere goes on changing continuously and randomly. Therefore, apparent position of star is not sleady, but it changes slighty. Therefore, the stars look twinkling (Figure 3.12).

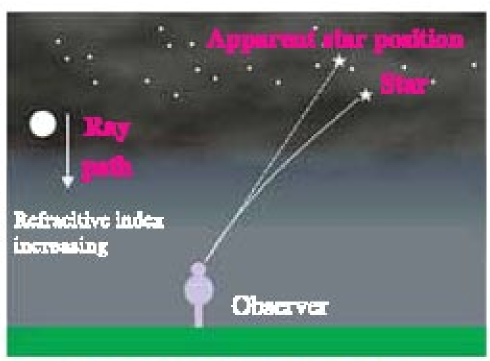


Fig. 3.12 : Twinkling of stars

The planets are nearer to earth so they can act as extended sources. That means they are considered as a collection of point sources due to which the twinkling does not occur and hence, the planets do not twinkle.

Early sunrise and delayed sunset :

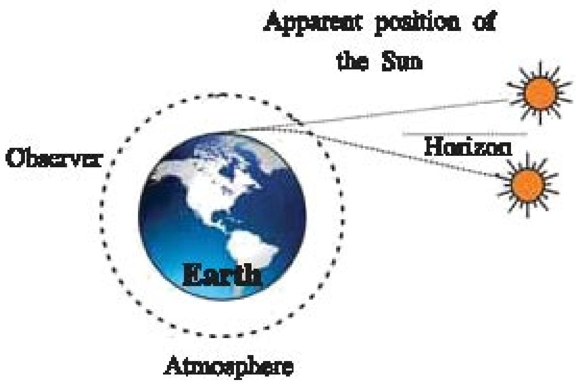


Figure 3.13 : Actual and apparent position of sun at sunrise.

The sun is visible to us about two minutes before the actual sunrise and two minutes after the actual sunset because of the refraction of the light by an atmosphere.

Actual sunrise means actual appearance at the horizon by the sun. Figure 3.13 shows actual and apparent positions of sun with respect to horizon.

When the sun is below the horizon, sunlight reaches to our eyes after being refracted in the atmosphere. Thus, the sunrise is experienced to be two minutes earlier. In the same way when the sun moves below the horizon, it is seen for two minutes after sunset.

Thus, the duration of the day increases by four minutes.

3.7 Scattering of Light

The deflection of light by minute particles and molecules in all the directions is known as scattering of light.

The colour of scattering light depends upon size of scattering particles. Due to the small size, minute particles scatter the light of small wave length such as blue colour. The particles with bigger size scatter the light of larger wavelength. If the size of scattering particle is much bigger the scattering light appears white.

Tyndall effect :

The earth's atmosphere is a heterogenous mixture of smoke particels, tiny water droplets and air particles. When light falls on such colloidal particles, the path of light beam becomes visible. This phenomenon is known as Tyndall effect. The light rays reach us after the deflection of light in all the directions from these particles.

When a fine beam of sunlight enters a smoke filled room through a small hole, a path of beam becomes visible due to this phenomenon. When the sunlight enters a canopy of dense forest, Tyndall effect is also seen due to the scattering of light through the tiny water droplets in mist. Some times the smoke emitted by the combustion of engine oil apperars blue in colour due to the Tyndall effect. This phenomenon is devloped commercially to determine size and density of aerosol and other colloidal particles.

Blue Colour of clear Sky :

The molecules of air and other fine particles in the atmosphere have their size smaller than the wavelength of visible light. These particles are more effective in scattering of light of visible shorter wavelength at the blue end than the light of longer wavelength at the red end. The wavelength of red coloured light is about 1.8 times more than that of blue colour. Thus, when sunlight passes through the atmosphere, the fine particles in the air scatter blue colour more strongly than red; so that sky appears blue. If the earth had no atmosphere, the sky would have appeared dark in the absence of scattering.

Why the signal lights for danger are red in colour ?

The red coloured light scatters least by fog or smoke so it can be seen from a long distance. Therefore, it is used in signals showing danger.

Reddish colour of the sun at sunrise and sunset :

To understand the reddish colour of sun at sunrise and sunset, we consider the following activity :

Activity : 5

- Place a strong source (S) of a white light at the focus of convex lens. (L_1) as shown in figure 3.14 to produce a parallel beam of light.
- Allow the light beam to pass through a tranparent glass vessel (V) containing clean water.
- Now allow the beam of light to pass through the circular hole (C) made in card-board and obtain sharp image of the circular hole on screen using second convex lens (L_2).
- Dissolve 100 g of sodium thiosuphate in about 1 litre of clean water in tank. Add 1 to 2 ml of concentrated sulphuric acid to water.
- What will be your observation ?

After some time you will see blue colured light when looking from side of a vessel and the crimson red colour will be seen on screen.

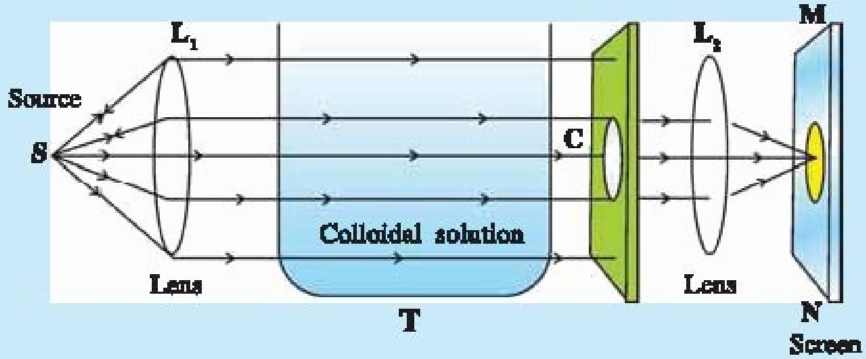


Fig. 3.14 Experimental arrangement for the observation of scattering of light through colloidal solution

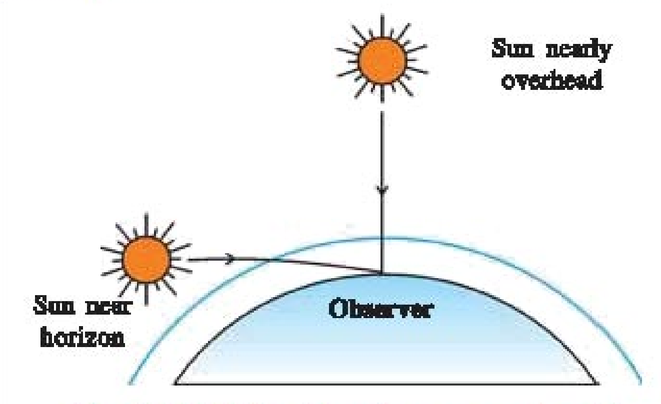


Fig. 3.15 Reddish colour of sun at sunrise and sunset.

The conclusion of this activity is that, the vessel is seen blue coloured while looking from one side due to more scattering of blue colour among white light, while the light of reddish colour (longer wave length) is less scattered so that it reaches to the screen and the screen appears reddish.

White light coming from sun has to travel more distance in the atmosphere before reaching to the observer. During this, the scattering of blue light takes place so that the light corresponding to reddish colour reaches to the observer and hence sun appears reddish. The similar situation also results at sun set. Rising and setting of full moon from the horizon appears reddish due to this reason.

For Information Only

Dr. Chandrashekhar Venkat Raman presented his paper "Scattering of light." on February 28, 1928. For this outstanding work he was given Nobel Prize in 1930. He was the first Nobel Prize winner in Physics from India. Government celebrates National Science Day on February 28 every year in his memory.

Various types of scattering based upon size of scattering particles are shown as under :

(i) Rayleigh scattering (ii) Mie scattering (iii) Tyndall scattering (iv) Brillouin scattering (v) Scattering of X-rays by crystal planes (vi) Raman scattering

Dr. Chandrashekhar Venkat Raman

3.8 Total Internal Reflection of Light

When a ray of light travels from optically denser medium to optically rarer medium, it bends away from the normal at the surface separating two media.

As the angle of incidence increases, the angle of refraction also increases and the ray of light moves farther away from the normal after refraction. The angle of incidence at which the angle of refraction is 90° is called critical angle (C). For the angle of incidence greater than cirtical angle, the light is completely reflected in the denser medium. The surface separating these two media acts like a "mirror". This phenomenon is known as total internal reflection of light (Fig.3.16).

The sparkling of diamond is also due to total internal reflection. The optical fibres used in signal commnication also work on this principle.

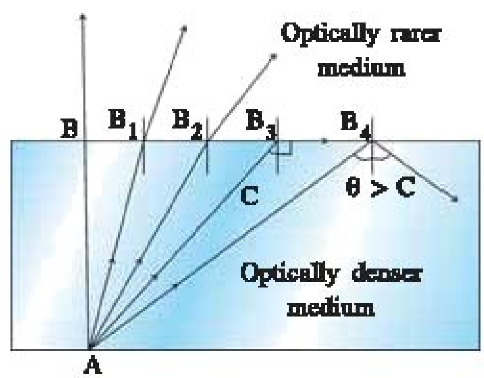


Fig. 3.16 Total internal reflection of light

Mirage formation :

Mirage is an optical illusion usually seen in desert. It is also seen on coal tar road during summer. In summer, the air near the surface of the earth is hotter than the air above it. Therefore, the air near the earth is rarer than that above it. So as we move up above the surface of the earth, the refractive index increases continuously.

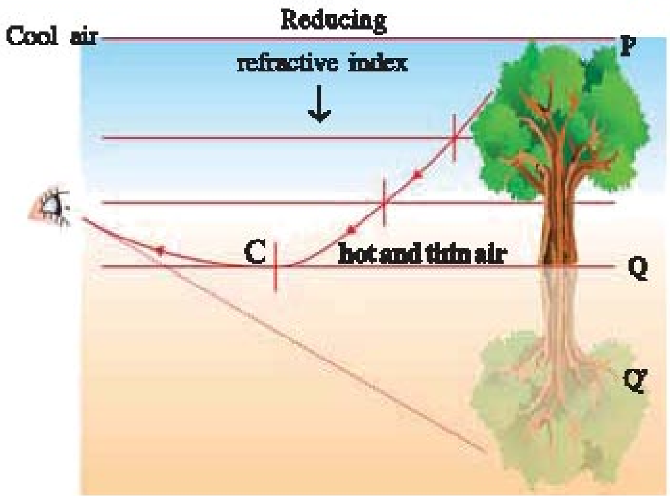


Fig. 3.17 Mirage Formation.

As shown in figure 3.17, the light rays coming from a point of a tall object like a tree pass through the air of gradually decreasing refractive index towards the ground, light rays bend gradually more and more away from the normal and their angle of refraction increases gradually so that they enter observer's eye after the total internal reflection occurs. Thus, the virtual and inverted image of an object appears to be as it is reflected from the water surface.

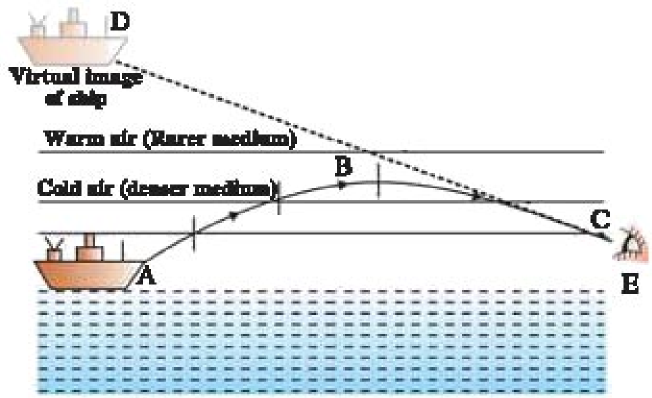


Fig. 3.18 Looming caused by total interval reflection

Looming is such a kind of mirage observed in very cold regions in which distant object appears to be hanging mid way in the air. It is produced by the total internal reflection of light (in downward direction) caused by atmospheric refraction. The looming produces virtual and erect image of an object above horizon where the warmer (optically rarer) air remains above the colder (optically denser) air in the atmosphere (Figure 3.18).

What have you learnt ?

- The splitting of white light into its constituent colours is known as dispersion of light.
- The violet coloured light is deviated maximum and the red coloured light is deviated minimum through the glass prism.
- If all the colours of light are reflected from the object, then it is seen white. If all the colours of light are absorbed by the object, it will appear black.
- Red, green and blue are primary colours.
- Magenta, yellow and cyan are primary pigments.
- The ability of an eye to adjust focal length of the eye-lens as per requirement is known as accommodation power of an eye.

- The minimum distance at which the nearby object can be seen clearly without contraction of an eye-lens is called least distance of distinct vision. It is also known as near point of an eye.
- The far distance up to which an eye can see the object clearly is known as far point of an eye. Generally, far point is at an infinite distance.
- An accommodation power of an eye for the person with normal vision is from 25 cm to infinity.
- The focal length of an eye-lens can be changed with the help of cilliary muscles.
- If the eye-lens can not become thin as per requirement, the defect of nearsightedness occurs. This defect can be corrected using a concave lens of appropriate power.
- If the eye-lens can not become thick as per requirement, the defect of far sightedness occurs. This defect can be corrected using a convex lens of an appropriate power.
- Because of the increasing age of a person, the cilliary muscles weakens and the elasticity of an eye-lens is reduced, so sometimes the nearby as well as far distant objects can not be seen clearly. This type of defect is called presbyopia. It is corrected using bifocal lens of appropriate power.
- A rainbow is caused by the dispersion, internal reflection and refraction of sunlight by tiny water droplets present in the atmosphere.
- When the light ray passes through the atmosphere, it gets refracted continuously due to the continuous change in density of atmosphere. This phenomenon is known as atmospheric refraction of light.
- The sun appears two minutes earlier than its actual sunrise and two minutes later than its actual sun set.
- The deflection of light by minute particles and molecules in all the directions is known as scattering of light. The phenomenon of scattering depends upon the colour of light and the size of scattering particles.
- The scattering by minute and fine particles is more for the light of smaller wavelenght i.e. for blue coloured light. The particles of large size scatter the light of larger wavelength by more amount.
- When a ray of light travels from denser medium to rarer medium, the angle of incidence at which the angle of refraction of light will be 90°, which is known as critical angle.
- Mirage is an optical illusion generally observed in hot region due to total internal reflection.
- Looming is an optical illusion observed in cold region in the atomosphere above horizon due to the total internal reflection of light.

EXERCISE

1. Select the proper choice from the given multipule choices :

(1) By which optical phenomenon, the splitting of white light into seven constituent colours occur ?

(A) Refraction (B) Reflection (C) Dispersion (D) Interference.

(2) Which colour of light deviates maximum in the dispersion of white light by prism ?

(A) Violet (B) Blue (C) Green (D) Red

(3) Which of the following are the primary colours ?

(A) Red, Blue, Yellow (B) Red, Green, Violet.

(C) Yellow, Green Blue (D) Red, Green, Blue.

(4) Which of the following are primary pigments ?

(A) Yellow, Green and Magenta (B) Magenta, Yellow and Cyan

(C) Blue, Green and Violet (D) Red, Green and Yellow.

(5) In human eye, the image of an object is formed at ----------------

(A) Iris (B) Pupil (C) Retina (D) Cornea

(6) Which is the complementary colours of blue colour ?

(A) Red (B) Yellow (C) Green (D) Magenta

(7) Which colour is obtained by mixing the blue and red colours ?

(A) Green (B) Magenta (C) Cyan (D) Yellow.

(8) The focal length of an eye lens is changed due to the action of ------------------.

(A) Pupil (B) Retina (C) Cilliary muscles (D) Cornea.

(9) Which colours are reflected when white light is incident upon blue pigment ?

(A) Yellow, Orange, Green (B) Violet, Green, Blue

(C) Violet, Yellow, Green (D) Yellow, Green, Blue

(10) -------------- lens is used to correct the defect of vision termed as presbyopia.

(A) Convex (B) Concave (C) Bifocal (D) Contact

(11) Which phenomenon does not play a role in the formation of rainbow ?

(A) Reflection (B) Refraction (C) Despersion (D) Absorption

(12) For which of the following cases, the total internal reflection of light will be possible ?

(A) Angle of incidence is less than critical angle.

(B) Angle of incidence is equal to critical angle.

(C) Angle of incidence is more than critical angle.

(D) Angle of incidence is equal to angle of refraction.

(13) Where is the image in eye formed for a person suffering from defect of near sightedness ?

(A) On retina (B) On backward region of retina

(C) On a region ahead of retina (D) On pupil.

(14) Which phenomenon is responsible for the twinkling of stars ?

(A) Atmospheric reflection (B) Atmospheric refraction

(C) Reflection (D) Total internal reflection.

(15) Due to which phenomenon of light does Tyndall effect result ?

(A) Reflection (B) Refraction (C) Scattering (D) Dispersion

(16) What is the time difference between actual sunset and apparent sunset ?

(A) 2 s (B) 20 s (C) 2 minute (D) 20 minute

(17) Which colour of light scatters maximum due to atmosphere ?

(A) Blue (B) Yellow (C) Green (D) Red.

(18) Which coloured light has minimum velocity in the glass prism ?

(A) Red (B) Green (C) Blue (D) Violet

2. Answer the following questions in brief :

(1) What is the dispersion of light ? Which are the colours of the spectrum obtained from the dispersion through a glass prism ?

(2) Write the name of primary colours of light. Write the name of colours obtained from their mixture ?

(3) What are called pigments ? Give the names of primary pigments.

(4) Write the function of cilliary muscles and retina in human eye.

(5) What is an accommodation power of an eye ? What is the least distance of distinct vision ?

(6) What is called atmospheric refraction ? Which phenomenon results from it ?

(7) Give the reason for two minute early sunrise.

(8) What is the scattering of light ? On what factors does it depend ?

(9) Why are the danger signal lights red in colours ?

(10) Why does the sun appear reddish at sunrise and sunset ?

(11) What is the total internal reflection of light ? Give its illustrations.

(12) What is looming ? How is it formed ?

3. Write answer of the following questions :

(1) Explain the superposition of primary colours of light with necessary illustration.

(2) Explain the function of main parts of an eye by drawing a simple sketch of it.

(3) Explain the formation of rainbow with a neat figure.

(4) Write a note on "twinkling of stars."

(5) Describe Tyndall effect.

(6) Why does the clear sky appear blue in colour ?

4. Answer the following questions in detail :

(1) Explain the dispersion of white light by a glass prism using necessary figure.

(2) Describe the fomation of mirage through an appropriate figure.

5. Answer the following questions pointwise :

(1) What is the defect of vision in the human eye ? State its types and explain in detail.

UNIT

4

ELECTRICITY

4.1 Introduction

Student, have a look at the drawing room of your house. You will see the appliances like television, fan, tube light etc. Now if you look at your kitchen you will find the appliances like refrigerator, microwave oven, mixer etc. If you peep into your study room you may see the instruments like computer, air conditioning machine. In all these appliances, the common thing is that they all are operated by electricity (electical energy). Now imagine that the electrictiy fails in our house ! Our situation will be worse. The electricity empowers the places like schools, offices, industries, hospitals etc. In modern age, the electrical energy among the different forms of energy has more importance in creating luxurious lives for human beings. Electrical energy can easily be stored as well as it can be easily transformed into other forms of energy.

In the present chapter, we shall study the concept of physical quantities like electric current, electric potential, resistance etc. Also we shall get some information about electrical energy and its uses.

Firstly, we shall know about the foundation stone of electricity namely an electric charge.

4.2 Electric Charge

We have studied in Standard 8 that the small pieces of papers can be attracted by a plastic comb after combing through dry hair. Similarly, the attractive force results when a glass rod rubbed with a silk and a plastic rod rubbed with a fur. In this process, the charges resulting on the glass and plastic rod are of opposite type. During the friction, the glass rod acquires positive charges while the plastic rod acquires negative charges.

Thus, the electric charges are of two types : Positive electric charge (proton) and negative electric charge (electron). Electric charge is an intrinsic property of electron and proton like mass, which is difficult to define.

In SI unit system, charge is measured in coulomb (C). Conventionally electric charge of proton is considered positive and the electric charge of electron to be negetive. But their magnitudes are the same.

Charge on proton $e = 1.6\times10^{-19}C$

Charge on electron $e = -1.6\times10^{-19}C$

During the interaction among the electric charges, repulsive force is exerted between two like charges (e.g. electron-electron or proton-proton) and the attractive force is exerted between two unlike charges (e.g. electron-proton). The magnitude of electric force between the charges can be calculated from the law devised by French Scientist Charles Coulomb which you will study in Standard 12.

4.3 Electric Current

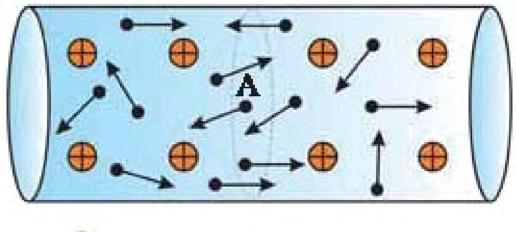
We are familiar with the flow of water. The quantity of water flowing in the river is called water current. Similarly, the amount of charge flowing through the conductor (e.g. Copper wire) is known as electric current.

In atoms, the electrons move around the nucleus whereas the protons remain binded. In the atoms of metallic materials, under the normal circumstances the attractive force between the valence electrons (electrons of the outermost orbit) and the nucleus (positive electric charge) is comparatively very small.

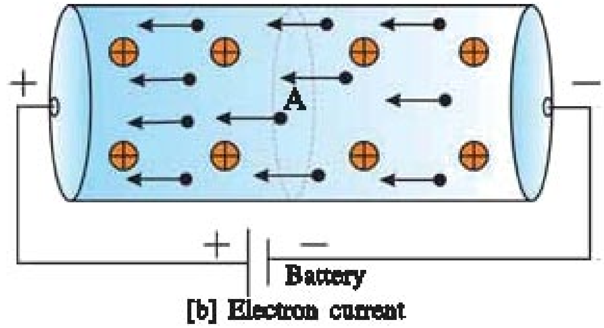
During the formation of metallic materials, these electrons get separated from their parent atoms and move in a random manner. Such electrons are known as 'Free electrons.'

Such free electrons are responsible for the conduction of electric current. Metallic materials like copper, silver and aluminium have plenty of such free electrons. The conduction of an electric current can easily take place in such materials. So they are called "Conductors." The materials like rubber, glass, plastic do not have free electrons so the conduction of electric current through them is not possible. So they are called "Insulators."

In Figure 4.1 (a), the random motion of free electrons in a conducting wire is shown. The motion of electrons is uniform in all the directions. Now think about any one cross-section A which is perpendicular to this conducting wire. In any given interval of time, the number of electrons moving to the right side of cross-section equals to that moving to the left, so that the net quantity of electric charge passing through cross-section is zero. Therefore, the electric current is not formed even though there is a motion of free electrons in conducting materials. As shown in Figure 4.1 (b), if the energy is provided to the conducting wire through the battery, the flow of free electrons can be obtained in a conducting wire from negative terminal to positive terminal of battery. Thus, the net quantity of electric charge passing through the cross-section A does not remain zero and the electric current is said to be formed in a conductor.



[a] Random motion of electron



[b] Electron current

Fig. 4.1 Electric current in a conductor

Earlier, scientists believed that the electric current results only due to the motion of positive charges, so the direction of motion of positve electric charges, was considered as the direction of electric current. But after the invention of an electron by J.J. Thomson (1856-1940), it was to know that the electric current in the conductors results due to the motion of electrons. At present, we also take the direction of electric current in the direction of motion of positive electric charge which is known as conventional electric current. Thus, the direction of conventional electric current is oppsite to the direction of flow of electrons.

After this primary explanation we shall define electric current.

"Electric current means rate of flow of an electric charge."

That means, the net quantity of an electric charge flowing through any cross section of conductor is defined as electric current.

$$\text{Thus, electric current} = \frac{\text{Quantity of electric charge}}{\text{time}}$$

If Q is the amount of electric charge passing through any cross section of conductor in time t,

$$I = \frac{Q}{t} \qquad \text{... ... ... (4.1)}$$

Thus from above equation (4.1), if the quantity of electric charge equals to one coulomb passing through the conductor in one second, the electric current of one ampere (1A) is said to flow through the conductor.

In SI system, the unit of electric current is coulomb/second (C/s). In the name of French Scientist Andre Ampere, it is also represented in Ampere (A)

The small units of electric current are milliampere mA and microampere (μA)

$$1 \text{ mA} = 10^{-3} \text{ A}$$

$$1 \text{ } \mu\text{A} = 10^{-6} \text{ A}$$

The electric current flowing through the conductor is measured by an instrument called 'Ammeter.'

If the number of electrons passing through the cross-section of conductor in time t equals to n, then the quantity of charge passing through the cross-section will be

$$Q = ne$$

Equation (4.1) can also be represented as

$$I = \frac{ne}{t} \qquad \text{... ... ... (4.2)}$$

where $e = 1.6 \times 10^{-19}$ C, charge of an electron.

Illustration 1 :

If an electric bulb burns on 0.5 A current for 1 hour, how much electric charge will pass through it ? ($e = 1.6 \times 10^{-19}$ C)

How many electrons will pass through it ?

Solution : $I = 0.5$ A, $t = 1$ Hour $= 3600$ s

From equation (4.1)

$$Q = I \times t$$
$$= 0.5 \times 3600$$
$$= 1800\ C$$

From Q = ne

no of electron passing through the bulb

$$n = \frac{Q}{e}$$
$$= \frac{1800}{1.6 \times 10^{-19}}$$
$$= 1125 \times 10^{19} = 1.125 \times 10^{22} \text{ electrons}$$

Illustration 2 :

While connecting a torch with battery, an electric current of 64 mA flows through the bulb. If this torch glows for 10 min, how may electrons will pass through the bulb ?

(charge of electron = e = 1.6×10^{-19} C)

Solution : $I = 64\ mA = 64 \times 10^{-3} A$, $t = 10\ min = 10 \times 60 = 600\ s$, $e = 1.6 \times 10^{-19}\ C$

Electric current $I = \frac{ne}{t}$

No of electrons = $\frac{I \times t}{e}$

$$n = \frac{64 \times 10^{-3} \times 10 \times 60}{1.6 \times 10^{-19}}$$
$$= 24000 \times 10^{16}$$
$$n = 24 \times 10^{19} \text{ electrons.}$$

4.4 Electric Potential and Electric Potential Difference

Electric Potential : We have seen that the flow of electric charge is necessary to obtain an electric current. How can this electric charge be made to flow in a conductor ?

To understand this, we shall first understand the flow of water.

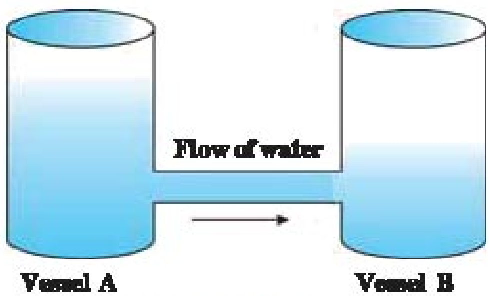


Fig. 4.2 Flow of water

As shown in Figure 4.2, pour more amount of water in vessel A and less amount of water in vessel B. Now when these vessels are connected through a tube, the water flows from vessel A to vessel B.

Here, the water pressure is more in vessel A and the water pressure is less in vessel B.

Thus due to the pressure difference, the water flows through the tube.

In the similar way, if we produce the electrical potential difference, then the electric current can be obtained. This difference in the electric potential is known as electric potential difference. We shall discuss electric potential first.

On bringing some electric charge near any other charge, an attractive or repulsive force exerts on it. Thus, the work is to be done against this force keeping a charge in equilibrium and to move another near or far from it. This work is stored in the form of potential energy. This work done on the charge is called as an electric potential. Electric potential is defined as under :

"The work required to bring the unit positive charge from infinity to any point against the electric force is known as electric potential at that point."

$$\text{Electric potential} = \frac{\text{Work done (W)}}{\text{Electric charge (Q)}}$$

Electric potential is represented in voltage in the memory of Italian Scientist Alexandro Volta. Its symbol is V.

$$\therefore V = \frac{W}{Q}$$

The SI unit of electric potential is joule/coulomb or volt (V).

Electric potential difference :

In practice, electric potential has no importance, but changes in electric potential are important which are defined as under :

"The electric potential difference between any two points A and B in an electric field means the work done to bring the unit positive charge from point A to B against the electrical force."

$$\text{Electric potential difference (V)} = \frac{\text{Work to be done (W)}}{\text{Electron charge (Q)}}$$

$$\therefore V = \frac{W}{Q}$$

Electrical potential difference, in general, is known as voltage. Its SI Unit is joule/coulomb or volt.

If the work done to bring 1 coulomb electric charge from one point to other is 1 joule, then the potential difference between these two points is called 1 volt.

$$1\,\text{volt} = \frac{1\ \text{joule}}{1\ \text{coulomb}}$$

The electric potential difference is measured with the device called **voltmeter.** The voltmeter is connected in parallel across two points of which the potential difference is measured.

Now, we shall understand from the activity that how potential difference is produced from the battery.

Activity : 1

Volta's Cell :

As shown in Figure 4.3, take solution of dilute sulphuric acid (H_2SO_4) in a beaker. Dip one copper plate and another zinc plate in the solution in such a way that they do not touch each other. These two plates get electrically charged due to the process between these two plates and the solution. The positive charge at copper plate and negative charge at zinc plate get deposited. Thus electric potential difference is produced between two plates. Positive charge plate is called positive pole of battery or anode and the negatively charged plate is called negative pole of battery or cathode. Such simple battery was invented by Italian Scientist Alexandro Volte (1745-1827). Therefore it is also known as Volta's cell.

Now connect a small bulb between these two poles of a battery. See what happens.

You will see that the bulb will light up. Here the electrons leaving negative terminal of battery move towards positive pole of battery by forming an electric current in the bulb. The bulb lights up due to this electric current. Thus, in bulb the electron flows from negative to positive pole. But the direction of conventional current is opposite to flow of electron, so it is said that it flows from positive toward negative pole of battery.

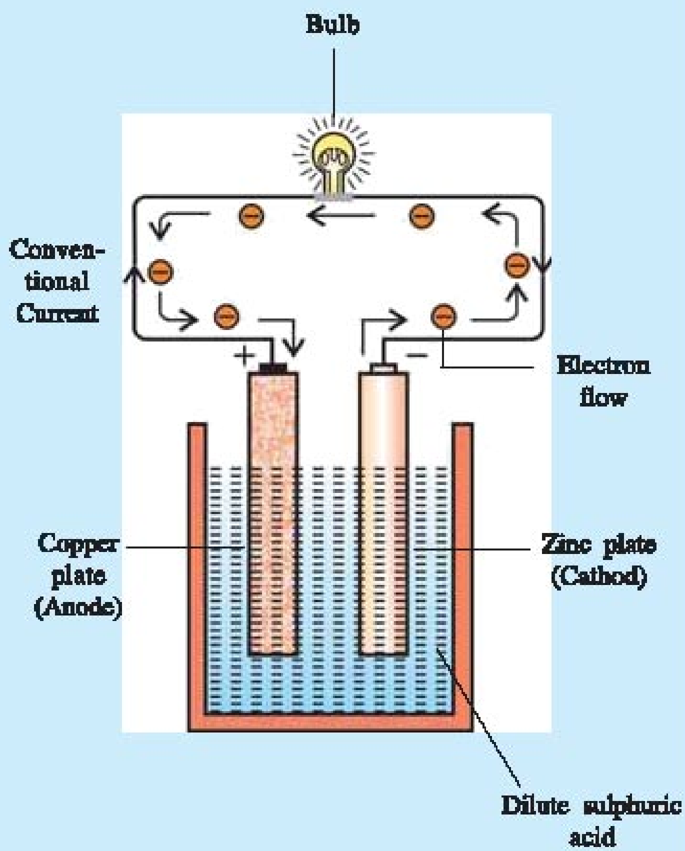


Figure 4.3. : Volta's electric cell

The electrons deposited at anode go back to cathode by taking energy form chemicals and enter the conductor. Thus, the function of battery is to give energy to electrons continuously and to flow the electric current continusly by keeping them in motion.

Thus, volta's cell converts chemical energy into electrical energy. By connecting more than one batteries in series the large electric potential is obtained and large amount of current is obtained in a conductor

Illustration 3 :

How much work is to be done to take 2 C electric charge form the potential of 6 V to the potential of 12 V ?

Solution : Q = 2 C

Electric potential difference $V = 12\ V - 6\ V = 6\ V$

$$\text{Now} \quad V = \frac{W}{Q}$$

$\therefore$ Work $W = VQ = 6 \times 2 = 12\ J$

4.5 Electric Circuit and Symbols

When electrical components such as battery, key, bulb, etc are connected through a conducting wire, then such an arrangement is called electric circuit. The electric bulb glows due to the formation of close loop of circuit. In the following Figure 4.4, electric circuit is shown by representing electrical components with their symbols :

The useful symbols for electric circuit are given in the following Table 4.1

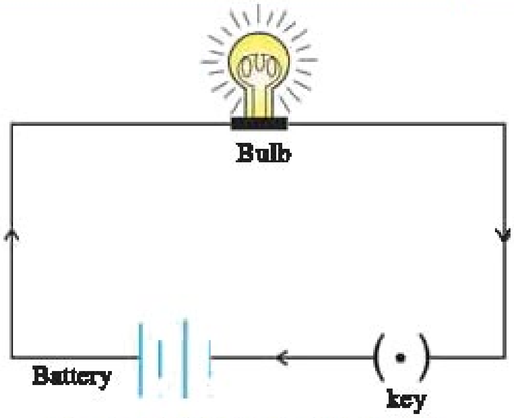
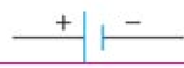
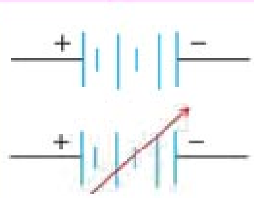
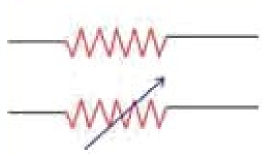
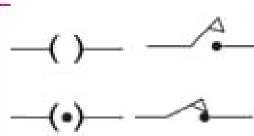
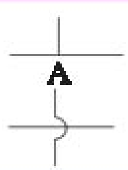


Figure 4.4 Simple electric circuit

Table 4.1 Some useful symbols for electric circuit

No.	Component	Symbol	Description
1.	Electric cell		Gives electrical energy to circuit
2.	Battery (Combination of electric cells)		Gives electrical energy to circuit Variable battery whose voltage value can be changed as per need
3.	Resistance		Provides resistance in the path of electric Current Variable resistor
4.	Key		Key (When open) Key (When closed) It is used to switch on or off.
5.	Connection of conducting wire		Two conducting wires connected at A Two wires passing above each other but not connected.
6.	Galvanometer		Device to detect the presence of electric current
7.	Ammeter		Device to measure an electric current
8.	Voltmeter		Device to measure electric potential difference

4.6 Ohm's Law

Is there a relation between the current (I) passing through the conductor and the potential difference (V) resulting across two ends ? German scientist George Ohm (1789-1854) derived the relation between current (I) and voltage (V) which is known as ohm's law. Perform the following activity to understand this relation.

Activity : 2

For this activity, take 0.5 meter long nichrome wire, four to five batteries of 1.5 V, Voltmeter, Ammeter and key.

As shown in Figure 4.5, first connect nichrome wire (Nichrome is an alloy of nickel, chromium, manganese and iron) with 1.5v battery and ammeter. Now connect the voltmeter between its two ends.

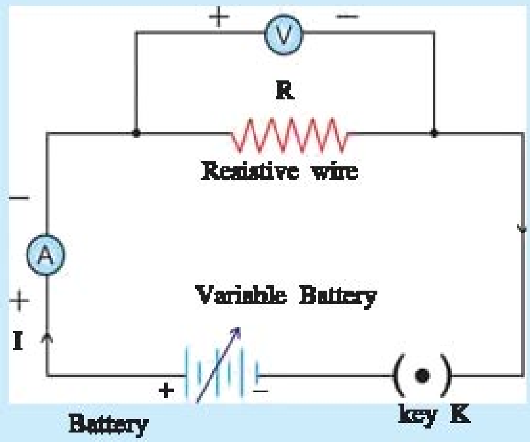


Fig. 4.5 Electric circuit for ohm's law

This experiment can also be perfomed by connecting bulb instead of nichrome wire. Now when the key is on, the electric current will flow through the wire. Measure the magnitude of the current in ammeter and the potential difference across its two ends in voltmeter and note in the observation table. Now connect two batteries instead of one and note the magnitudes of current (I) and voltage (V). In this way, repeat the experiment by connecting three batteries and there after four batteries.

Observation table :

Number	No of Batteries	Voltage across two ends of wire (V)	Current flowing through wire (I)	V/I
1	1			
2	2			
3	3			
4	4			

Now, from the observations, draw the graph of I versus V. What is the type of this graph ?

This graph will be a straight line passing through the origin (Figure 4.6).

The following points are concluded from the graph :

(i) The electric current in the conductor increases in same proportion with the increase in voltage.

(ii) I – V graph is a straight line.

(iii) The ratio of V and I remains constant every time.

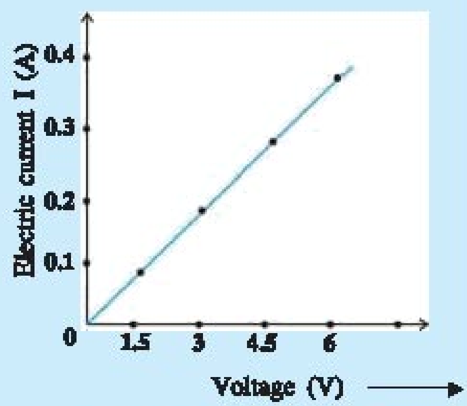


Fig. 4.6 Graph of I versus V

From this type of experiment, Ohm deuced the relation between electric current (I) and voltage (V) which is termed as Ohm's Law. It is stated as under.

Ohm's Law : "In the definite physical situation the electric current flowing through the conductor is directly proportional to the potential difference applied across it.

That means, $I \propto V$

It is also written as, $V \propto I$

$\therefore V = IR$

Where the proportionality constant R represents the resistance of the circuit.

From above equation,

$$\text{Resistance (R)} = \frac{\text{Voltage (V)}}{\text{Electric current (I)}}$$

The SI unit of resistance is volt/ampere which is known as 'ohm'. Its symbol is Ω(omega).

$\therefore$ 1 ohm = 1 volt / 1 ampere

When 1 volt potential difference is applied across the conductor and 1 ampere current flows through it then resistance of the conductor is said to be 1Ω.

The symbol  is used to represent the resistance in the electrical circuits.

The resistance of substance depends upon the kind of substance and its physical situation (e.g. temperature). In metallic substance, the resistance increases with the increase in temperature. In a conductor, the free electrons collide with the positive ions during their motion so that their motion gets opposite. Thus, the motion of electrons means the motion of electric current get opposed which is called resistance of conductor (R).

The metallic substance such as Copper, Aluminium have less resistance. Therefore, we use the copper wire as a conducting wire. The resistance of insulators is very large. The alloys like nichrome are used to make resistive wires. The resistors used in instruments like TV, Radio etc are made from the mixture of carbon and graphite.

Illustration 4 :

If an electric bulb connected to 220 V line draws an electric current of 0.5 A, then what will be the resistance of filament of a bulb ?

Solution : I = 0.5 A, V = 220 V

According to ohm's law, $R = \frac{V}{I} = \frac{220}{0.5} = 440\ \Omega$

Illustration 5 :

When an electric heater is applied 120 V, an electric current of 2 A passes through it. If the heater is applied 240 V, how much electric current will flow through it ? What will be the resistance of the coil of a heater ?

Solution : $V_1 = 120$ V, $I_1 = 2$ A, $V_2 = 240$ V, $I_1 = ?$

Resistance of heater coil $R = \frac{V_1}{I_1} = \frac{120}{2} = 60\ \Omega$

Now, according to Ohms' law, $R = \frac{V_2}{I_2}$

$$\therefore I_2 = \frac{V_2}{R} = \frac{240}{60} = 4\ A$$

4.7 Resistivity

Activity : 3

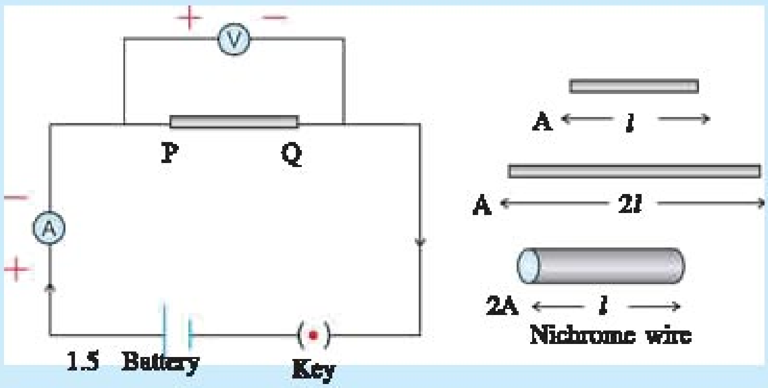


Fig. 4.7. The effect of resistance on its size.

(i) As shown in the Figure 4.7, connect the resistance wire (nichrome wire) of cross section (A) and length *l* (e.g. 0.5 m) in the circuit between the points P and Q. Now measure the current (I) and voltage (V) by closing a key and determine the resistance R_1 from equation R = V/I.

(ii) Now connect the resistive wire of cross section A and length 2*l* (1m) in the circuit and determine its resistance as R_2.

(iii) In the same way take the resistive wire having cross-sectional area 2A and length *l* and determine its resistance as R_3.

Give your conclusions about R_1, R_2 and R_3.

In the activity, you will get $R_2 = 2\ R_1$.

In this case, the area of cross section of wire is double, so its resistance is doubled. Now, for the resistance R_3, you will get $R_3 = \frac{R_1}{2}$. In this case, the length of wires *l* is the same, but the area of cross section of the third wire is twice compared to that of the first one. Therefore, its resistance to be obtained is half to that of R_1.

Thus, the magnitude of resistance depends upon the type and also on size of material.

The resistance of any conduction substance is directly proportional to length and inversely proportional to area of cross section of the substance.

If the length of conductor and its area of cross-section are represented as l and A respectively then,

$$R \propto l, \quad R \propto \frac{1}{A}$$

$$\therefore R \propto \frac{l}{A} \qquad \therefore R = \rho \frac{l}{A}$$

Here, ρ is called the resistivity of conducting material. From above equation $\rho = R\frac{A}{l}$

$$\text{The unit of } \rho = \frac{\text{Unit of resistance} \times \text{Unit of area}}{\text{Unit of length}}$$

$$= \frac{\Omega \times m^2}{m} = \Omega m$$

Table 4.2 represents resistance of some metals, semi-metals and insulators :

Table 4.2 Resistivity of some substances (at 20°C)

Type	Substance	Resistivity ρ (Ωm)
Metals	Aluminium	2.63×10^{-8}
	Copper	1.62×10^{-8}
	Silver	1.6×10^{-8}
	Iron	10×10^{-8}
	Tungsten	5.2×10^{-8}
Alloys	Manganin	44×10^{-6}
	Nichrome	100×10^{-6}
Insulators	Glass	$10^{10} - 10^{14}$
	Rubber (Hard)	$10^{13} - 10^{16}$
	Diamond	$10^{12} - 10^{13}$
	Paper (dry)	10^{12}

It is clear from Table 4.2 that the resistivities of conductors and alloys are less whereas it is very large for insulators. The resistivity of elements such as silicon (Si) and germanium (Ge) is more than conductors but less than insulators. So they are called semiconductors. Such elements are widely used in the fabrication of electronic components.

Illustration 6 : The resistance of a resistive wire having length l and area of cross-section A is 4 Ω. If the length of same type of wire is $l/2$ and the area of cross-section 2A, what will be the resistance of wire ?

Solution : For the first wire, $R = \rho\frac{l}{A}$, for the second wire, $R' = \rho'\frac{l'}{A'}$ From $l' = \frac{l}{2}$ and $A' = 2A$

$$\therefore R = \rho\frac{l/2}{2A} = \frac{1}{4}\rho\frac{l}{A} = \frac{1}{4} \times R = \frac{1}{4} \times 4 = 1\Omega$$

Illustration 7 :

The resistance of copper wire of length 2 m and 1.7 × 10^{-6} m^2 area of cross-section is 20×10^{-2} Ω. What is its resistivity ?

Solution : $l = 2$ m, $A = 1.7 \times 10^{-6}$ m^2, $R = 2 \times 10^{-2}$ Ω

$$\text{From } R = \rho \frac{l}{A}$$

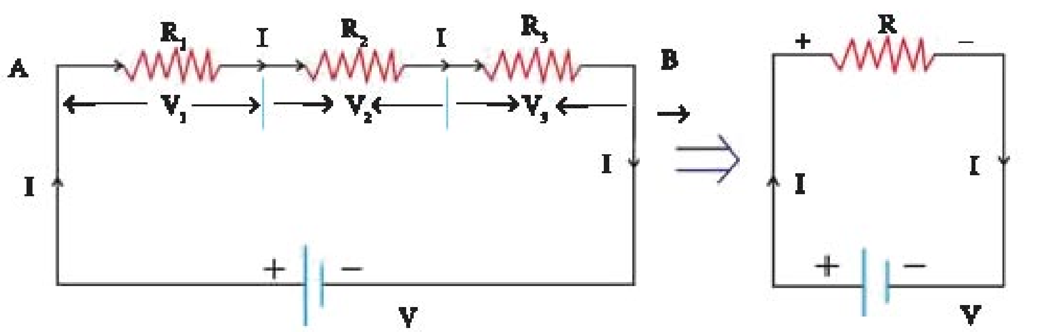
$$\therefore \rho = \frac{R \times A}{l} = \frac{2\times10^{-2}\times10^{-6}}{2} = 1.7\times10^{-8}\ \Omega m$$

4.8 Combination of Resistance

Students, have you seen your pocket radio from inside ? You will see the various resistors connected together in a complex manner. These resistors magnitude in the instrument (radio) control the current in the different circuits. For this, sometimes large magnitude and sometimes small magnitude of resistance are required. To get the desired magnitude of resistance, we connect some resistors in series or in parallel or in series and parallel both. Here we shall study about series and parallel connection of resistors.

(1) Series connection of resistors :

The resistors are connected across two points in the circuit in such a way that the current flowing through each resistor is the same and only one path is availble for it to flow, then the resistors are said to be connected in series.



(a) Electric circuit

(b) Equivalent circuit

Fig. 4.8 Series connection of resistors

In figure 4.8(a), three resistors R_1, R_2 and R_3 are connected in series across the points A and B.

Here, current (I) flowing through each of the resistors R_1, R_2 and R_3 is the same, but the total voltage of the battery V is divided according to the resistance values.

If the voltage drops across R_1, R_2 and R_3 are V_1, V_2 and V_3 respectively then,

$$V = V_1 + V_2 + V_3 \quad (4.8.1)$$

Now, if the resistor R instead of these three resistance R_1, R_2 and R_3 is connected in such a way that the current flowing through the circuit remains the same, then R is called equivalent resistance of the circuit. (Fig. 4.8 (b)).

For an equivalent resistor $V = IR$ (4.8.2)

According to Ohm's law,

R_1 voltage drops across, $V_1 = IR_1$ (4.8.3)

R_2 voltage drops across $V_2 = IR_2$ (4.8.4)

R_3 voltage drops across $V_3 = IR_3$ (4.8.5)

From (4.8.3), (4.8.4) and (4.8.5) $IR = IR_1 + IR_2 + IR_3$

$$\therefore\ R = R_1 + R_2 + R_3 \quad (4.8.6)$$

From this we say that the equivalent resistor R can be obtained by the summation of all the resistors connected in series.

We shall note some important points about the series connection.

(1) In this type of connection, the current flowing through each resistance is the same.

(2) The total voltage drops across all the resistors connected in series equals to the sum of voltage drops across each resistor.

(3) The magnitude of equivalent resitance is always greater than the largest resistance.

Illustration 8 :

In order to get the current 0.5 A in the circuit by connecting a bulb of resistance 20 Ω with 12 V battery how much should be the value of resistance connected in series ? What will be the voltage drop across the bulb ?

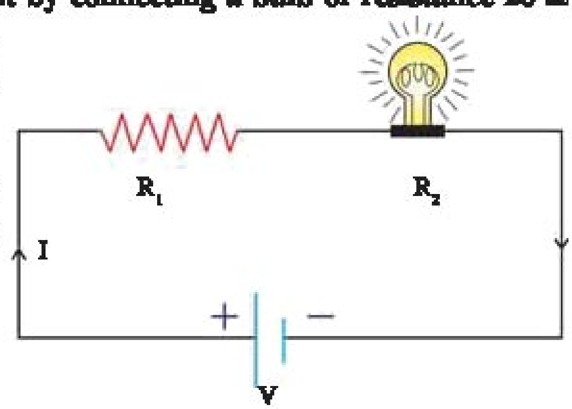


Fig. 4.9

Solution : If the resistance connected in series with bulb is R_1 and resistance of bulb is R_2 then, the circuit will be as shown in Figure 4.9.

$V = 12$ V, $I = 0.5$ A, $R_2 = 20\ \Omega$, $R_1 = ?$

using Ohm's law, $R = \frac{V}{I} = \frac{12}{0.5} = 24\,\Omega$

Here, bulb and R_1 are in series, therefore equivalent resistance

$R = R_1 + R_2$ ... ... (1)

Substituting the value of R and R_2 in equation (1)

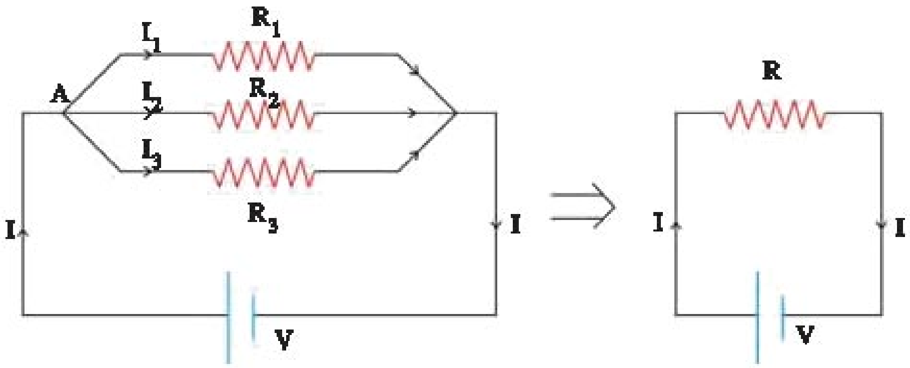
$24 = 20 + R_2$

$\therefore R_2 = 24 - 20 = 4\ \Omega$

The voltage drop across the bulb, $V_2 = I R_2 = (0.5)(4) = 2$ V

(2) Parallel connection of resistors :

When more than one resistances are connected across two points in the circuit such that more than one path are available for the current to flow and the voltage drops across two ends of each resistor are same, then the resistors are said to be connected in parallel between these two points.



(a) Electric circuit (b) Equivalent circuit

Fig. 4.10 Parallel connection of resistors

As shown in Figure 4.10(a), three resistors R_1, R_2 and R_3 are shown connected parallel across A and B. Here, one end of resistors are connected at common point A and the other ends are connected at another common point B. The electric current I at point A is divided into three parts. The current flowing through each resistor depends upon their resistance values.

Suppose the current flowing through resistors R_1, R_2 and R_3 are I_1, I_2 I_3 respectively, then the total electric current is equal to the electric current flowing through the circuit.

$$\therefore I = I_1 + I_2 + I_3 \qquad (4.8.7)$$

In parallel connection of resistors, the voltage drop across every resistor is equal to battery voltage V.

Therefore, according to Ohm's law,

$$I_1 = \frac{V}{R_1}, \quad I_2 = \frac{V}{R_2}, \quad \text{and} \quad I_3 = \frac{V}{R_3}$$

from equation (4.8.7) $I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$

Now, if one such resistor R instead of three resistors R_1, R_2 and R_3, is connected across the battery, the current flowing through the circuit will be same as I (Fig. 4.10 (b))

$$I = \frac{V}{R}$$

$$\therefore \frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\therefore \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \qquad (4.8.8)$$

Here, R is called the equivalent resistance of parellel connection of three resistors.

We shall note the following points for the parallel connection of resistors :

1. The reciprocal of equivalent resistance R is equal to the sum of reciprocal of individual resistors.

2. The voltage drop across each resistor remains the same.

3. The sum of the current flowing through each resistor equals to total current flowing through the circuit.

4. The magnitude of equivalent resistance is always smaller than the smallest resistance.

Illustration 9 :

The three resistors are connected in parallel with the 30 V battery. The electric current of 7.5 A flows through circuit from battery. If the values of two resistors are 10 Ω and 12 Ω, determine the value of the third resistor.

Solution : $V = 30\ V,\ I = 7.5\ A,\ R_1 = 10\ \Omega,\ R_2 = 12\ \Omega,\ R_3 = ?$

The equivalent resistance of circuit $R = \frac{V}{I} = \frac{30}{7.5} = 4\ \Omega$

Now, R_1, R_2 and R_3 are connected in parallel.

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\therefore \frac{1}{R_3} = \frac{1}{R} - \frac{1}{R_1} - \frac{1}{R_2}$$

$$= \frac{1}{4} - \frac{1}{10} - \frac{1}{12} = \frac{15-6-5}{60} = \frac{1}{15}$$

$$\therefore R_3 = 15\ \Omega$$

Illustration 10 :

For the circuit shown in Figure 4.11, determine the equivalent resistance between A and B. Also find the current flowing from the battery.

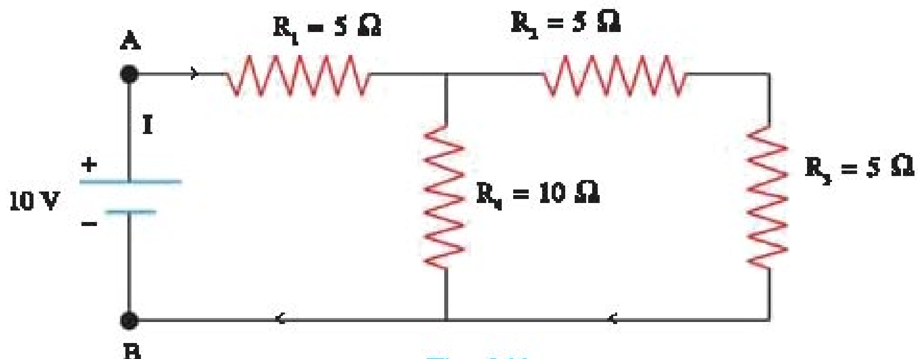


Fig. 4.11

Solution :

As shown in Figure 4.12 (a), R_2 and R_3 are connected in series, their equivalent resistance

$R' = R_2 + R_3$

$= 5 + 5$

$= 10\ \Omega$

Now R' is parallel with R_4 (Figure 4.12 (b)) Equivalent resistance,

$$\therefore \frac{1}{R''} = \frac{1}{R_4} + \frac{1}{R'}$$

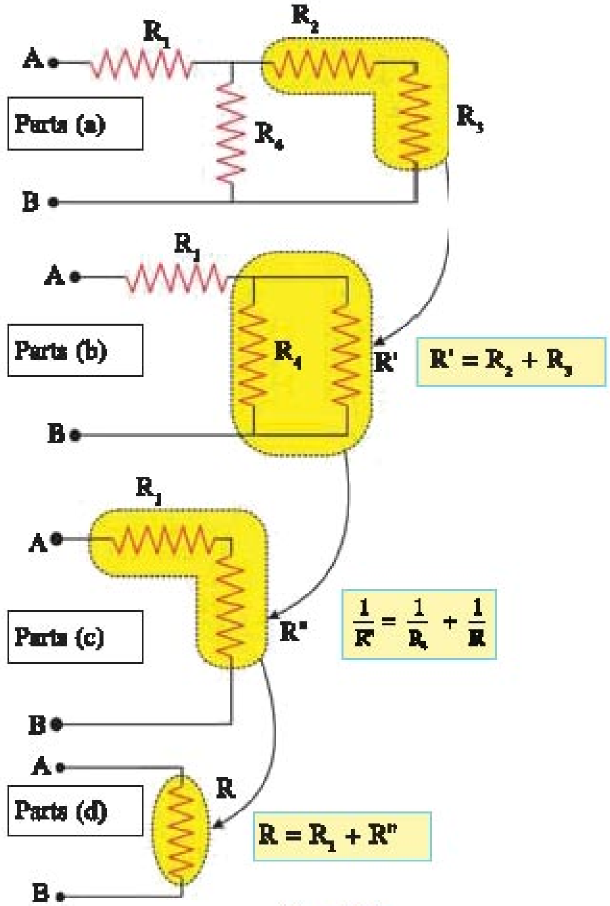


Fig. 4.12

or

$$R'' = \frac{R_4 \times R'}{R_4 + R'}$$

$$= \frac{10 \times 10}{10 + 10}$$

$$= 5\ \Omega$$

Now R" and R_1 are connected in series (Figure 4.12 (c)). Equivalent resistor across A and B,

$$R = R'' + R_1$$

$$= 5 + 5$$

$$= 10\ \Omega$$

The current flowing from the battery,

$$I = \frac{V}{R} = \frac{10\,V}{10\,\Omega} = 1\,A$$

Illustration 11 :

Determine the equivalent resistance between points A and B in the circuit :

Solution : First of all, R_1 and R_2 are in series.
$R' = R_1 + R_2 = 3 + 3 = 6\ \Omega$

Similarly R_3 and R_4 are in series

$R'' = R_3 + R_4 = 3 + 3 = 6\ \Omega$

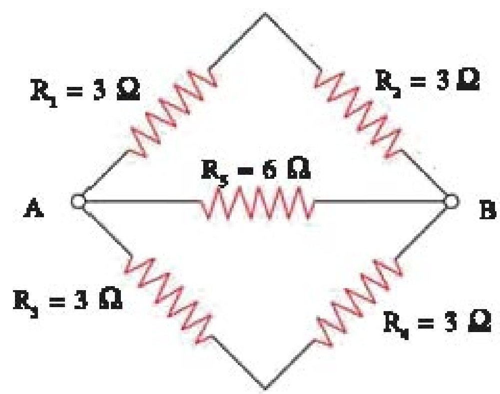


Figure : 4.13

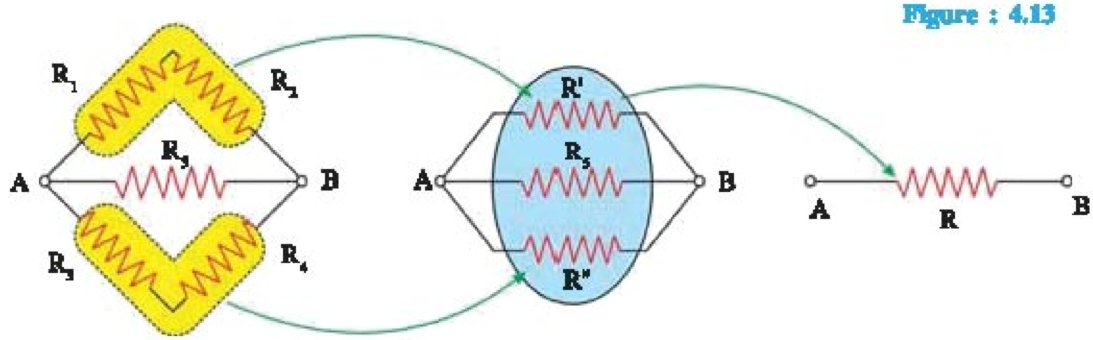


Fig. 4.14

Now, R_5, R' and R" are parallel between A and B

$$\therefore \frac{1}{R} = \frac{1}{R_5} + \frac{1}{R'} + \frac{1}{R''}$$

$$\therefore \frac{1}{R} = \frac{1}{6} + \frac{1}{6} + \frac{1}{6} = \frac{3}{6} = \frac{1}{2} \qquad \therefore R = 2\ \Omega$$

(3) Merits and demerits of series and parallel connections of resistors :

The total resistance of the circuit increases by connecting the resistors in series hence, the current decreases. Thus, to control the current in the circuit, series connection of resistors is useful. Moreover, the fuse is connected in series with 230 V AC mains as well as in electrical appliance and in the domestic electric connection. Therefore, whenever short circuit occurs in any electrical appliance, the fuse wire melts and stops electric current. As a result, damage of the electrical appliance can be prevented.

If the electrical appliances are connected in series, the applied voltage is divided, e.g. the three bulbs operating on 240 V when connected in series each gets 80 V. They cannot give the light efficiently because of this less voltage. In series connection, if fault occurs in one appliance or the circuit breaks, the current does not flow in the circuit and all other appliances stop working, e.g. if one of the 3 bulbs get fused, other bulbs do not light up.

But if these three bulbs are connected in parellel with 240 V supply, all the three bulbs get same voltage. If any one bulb gets fused, the current continues to flow through other two bulbs and they will work. Thus in the parallel connection break up does not occur. In our house, the appliances such as fan, bulb light, TV, refrigerator etc are connected in parallel with 240 V AC mains line. The equivalent resistance in the parallel connection of resistor decreases, hence, more current can be obtained.

4.9 Heating Effect of Electric Current

When we pass the electric current in the bulb, our experience says that after a while it becomes hot. In the same way, by flowing an electric current through electrical appliances like iron or heater, the heat is produced. Here, electrical energy is converted into heat energy which is known as heating effect of an electric current. In the same way the electrical energy is transformed into heat energy due to the resistance.

Electrical energy :

Suppose the electric current is flowing through some resistor (R). To flow this current continuously the battery has to provide energy to every electric charge. Now, the work required to keep the charge Q in motion by the battery of voltage V is,

$$W = VQ$$

From the definition of the electric current,

$$Q = I\,t$$

$$\therefore \quad W = V\,I\,t$$

According to Ohm's law, $V = I R$

$$\therefore W = (IR)(I)(t)$$

$$\therefore W = I^2Rt$$

Thus, the current flowing through a resistor R for time t is I, the electrical energy consumed to be W which is converted into heat energy.

$$\therefore \text{Heat energy (H)} = I^2Rt$$

The obove equation is called **Joule's Law.**

Thus the energy produced in a resistor is,

(1) directly proportional to the square of current passing through it.

(2) directly proportional to the resistance for a given current.

(3) directly proportional to the time t for a given current and resistance.

The SI unit of an electrical energy or heat energy is joule (J).

The thermal effect of an electrical current is used in many instruments used in a daily life. e.g. electric heater, electric iron, water heater, toaster, oven etc. Though in some other appliances like fan, computer, generator, electric motor etc, the heat generated due to the electric current is useless.

Electrical power :

"Electrical power means the rate of electric energy." That means the electrical energy consumed (or heat generated) in unit time is defined as an electric power.

It is denoted as symbol P.

$$\therefore \quad P = \frac{\text{Electrical energy consumed}}{\text{Time}}$$

$$= \frac{W}{t} = \frac{I^2 Rt}{t}$$

$$\therefore \quad P = I^2 R \qquad (4.9.1)$$

$$\text{or} \quad P = I V \quad (\because I R = V) \qquad (4.9.2)$$

$$\text{or} \quad P = \frac{V^2}{R} \quad (\because I = \frac{V}{R}) \qquad (4.9.3)$$

The SI unit of power is joule/second or watt (W).

If 1 A current flows through the circuit from 1V battery, the power consumed to be 1W.

From equation (4.9.2)

$$1 \text{ watt} = 1 \text{ volt} \times 1 \text{ ampere}$$

$$= 1 \text{ VA}$$

Practical unit of electrical energy :

According to definition of electrical power,

$$P = \frac{W}{t}$$

$\therefore \quad W = P \times t$

$\therefore \quad$ 1 joule = 1 watt × 1 second

The unit 'watt sec' is smaller for electrical energy, so in practice a unit kilo watt hour (kWh) is used.

1 kWh = 1000 watt × 3600 second

$\therefore \quad$ 1 kWh = 3.6×10^6 joule

The electricity which you use in your house for domestic purpose is calculated in kWh. It is called "unit."

$\therefore \quad$ 1 unit = 1 kWh = 3.6×10^6 joule

When 1000 W bulb is on for 1 hour, the energy consumed is equal to 1 unit.

Illustration 12 :

The 5 A current flows through an electric iron. If the resistance of electric iron is 44 Ω then how much energy will be consumed in 5 minutes ?

Solution : I = 5 A; R = 44 Ω, t = 5 min = 5 × 60 = 300 s

Electrical enerey $\quad W = I^2 R t$

$= (5)^2 (44) (300) = 330000 = 3.3 \times 10^5$ J

Illustration 13 :

A bulb is marked 220 V, 100 W, what will be the resistance of this bulb ? What will be the current passing through it when connected across 220 V supply ?

Solution : V = 220 V, P = 100 W, R = ? $\quad$ I = ?

From $P = \frac{V^2}{R}$, $\quad R = \frac{V^2}{P}$

$$= \frac{220 \times 220}{100} = 484 \ \Omega$$

From P = V I

$$I = \frac{P}{V} = \frac{100}{220} = 0.45 \text{ A}$$

Illustration 14 :

In a house, if three bulbs of 100 W, 60 W and 40 W are used 2 hours per day, how many units of electrical energy will be consumed in 30 days ?

Solution : Evergy consumed per sec $\quad$ P = 100 W + 60 W + 40 W

= 200 W

$\therefore$ Energy consumed per day $\quad = P \times t$

$= 200 \times 2 \times 3600$ W

$= 144 \times 10^4$ W

$$= \frac{1440 \times 10^3}{1000 \times 3600}$$

$$= 0.4 \text{ kWh}$$

∴ Energy consumed in 30 days $W = 0.4 \times 30$

$= 12$ kWh

Now, 1 unit = 1 kWh

∴ Energy consumed in 30 days = 12 kWh = 12 units

4.10 Chemical Effect of An Electric Current

The chemical reaction is responsible to get the electrical current means the chemical energy is converted into electrical energy by the battery. Then, can electrical energy be used for the chemical reaction ? Can electric current pass through any chemical ? To understand this let us perform the following activity :

Activity : 4

Take two carbon rods (You may get the rods from the core part of a used up dry cell by breaking it.) Now dip these rods in to a beaker filled with dist. water. Connect small bulb, 12V battery and a key to these rods. What happens when the key is on ? Has the bulb glown ? You may have seen that bulb does not glow. Do not worry, now add some salt into water (or take a tap water instead of distilled water)

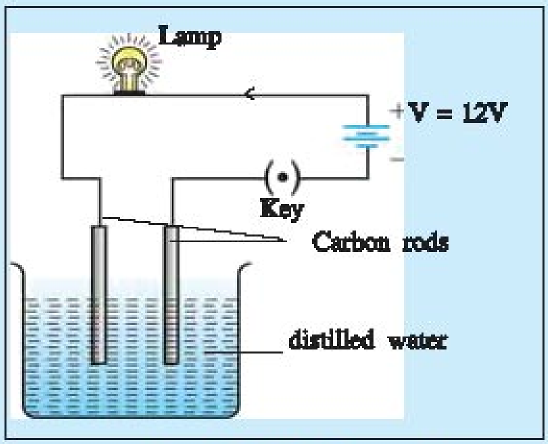


Fig. 4.15 Electric current through water

Now you can see that the bulb glows. Thus distilled or highly pure water does not conduct electricity. When a normal water which we use daily is conductor of electricity (That is why we should not touch the electric switch with the wet hand or foot). The solutions that conduct electricity are called "electrolytes." In the electrolytes, the electric current flows due to positive and negative ions.

Electroplating

You must have seen the metallic ornaments which are gold plated so as to look like real gold. The metals may be even copper plated or silver plated. This is carried through a process known as electroplating. To understand this, take a solution of copper sulphate ($CuSO_4$) in a beaker. In this solution, the iron spoon which is to be electro-plated and a copper plate are taken as electrodes and are connected with battery and key as shown in Figure 4.16. Pass the current in circuit for some time, you will observe that Cu is plated on metallic spoon. How did this happen ?

Here copper sulphate ($CuSO_4$) is taken as an electrolyte. On passing the current through this solution, it is decomposed into Cu^{+2} and SO_4^{2-} ions. As Cu^{+2} ion is positively charged, so it moves towards negative terminal i.e. metal spoon and deposits on iron spoon. Thus on iron spoon the plating takes place. Though there is no scarcity of Cu atoms because the copper atoms go into the solution from positive terminal i.e. copper plates, the above process is called electro-plating.

By the method of electropating, the layers such as copper, nickel and chromium are coated on the things of iron in order to protect them against rusting and to keep them shining.

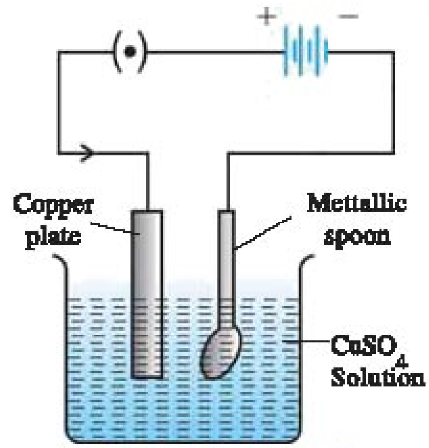


Fig. 4.16 Electroplating

Faradays laws of electrolysis :

On passing the electric current through the electrolytic solution, negative ions move towards positive terminal and the positive ions move towards negative terminal. The process of separating the ions is called electrolysis.

Michael Faraday (1791-1867), studied it in detail and gave two rules to calculate how much metal is deposited on the electrode in the process of electrolysis.

Faraday's First Law :

The mass of the substance (metal) deposited at cathode on passing the electric current through electrolytic solution is proportional to charge passing through it. $m \propto Q$

Faraday's Second Law :

For a given amount of current passed, the masses of different elements deposited on cathode is proportional to their chemical equivalent (e). Chemical equivalent of any atom is the ratio of atomic mass and its valency. $\left(\frac{m_1}{m_2} = \frac{e_1}{e_2}\right)$

What have you learnt ?

- **Electric charge :** Electric charge is an intrinsic property of electrons and protons situated in atom. Electric charges are of two types : (1) Positive electric charge and (2) Negative electric charge.
- **Electric current :** The net amount of electric charge flowing through any cross-section of conductor in unit time is known as an electric current.

  $$I = \frac{Q}{t}$$

  The unit of an electric current is ampere (A).

  The direction of conventional electric current is opposite to that of flow of electrons in the conductor.
- **Electric Potential :** The work required to bring the unit positive charge from infinity to any point in the electric field is known as electric potential at that point.

- **Electric Potential Difference :** The electric potential difference between any two points A and B in the electric field means work done to take unit positive charge from A to B against electrical force.

$$V = \frac{W}{Q}$$

The unit of electric potential and electric potential difference is J/C or volt.

- **Ohms' Law :** In the definite physical condition, the current passing through the conductor is proportional to the applied electric potential difference across the conductor (1 α V)

In the form of formula, $V = I R$ or $R = \frac{V}{I}$.

R is the resistance of conductor and its unit is Ω.

- The resistance of conductor depends upon the kind of material and its dimensions.

$$R = \rho \frac{l}{A}$$

where ρ = resistivity of material, l = length of resistive wire,

A = Area of cross-section of resistive wire

- **Series connection of resistors :** Connecting the resistors $R_1, R_2, R_3..., R_n$ in series, their equivalent resistance will be $R = R_1 + R_2 ..... + R_n$.

In the series connection of resistors, the current flowing through each resistor is the same, but the potential difference across each resistor is different (voltage drops).

- **Parallel connection of resistance :** Connecting the resistance $R_1, R_2, R_3..., R_n$ in parallel their equivalent resistance will be $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ... + \frac{1}{R_n}$

In this type of connection, the voltage drop across each resistor remains the same, where as the current flowing through them is different.

- **Elctrical Energy :** The energy consumed on passing the current (I) through the resistance (R) conductor for some difinite time (t) is $W = I^2 Rt = \frac{V^2}{R}t = V I t$.

The unit of electric energy is joule. Its conventional unit in practice is kWh or unit.

- **Electrical Power :** The electrical energy consumed in unit time is difined as an electric power (P). Its unit is watt. $P = \frac{W}{t} = I^2R = \frac{V^2}{R}$

- **Electroplating :** The process of depositing of one metal on another metal using the chemical effect of electric current is called electroplating.

The object on which the metal to be deposited is connected with negative terminal and the metal which is to be deposited is connected with the positive terminal of battery.

EXERCISE

1. Select the proper choice from the given multiple choices :

(1) The SI unit of electric charge is ......

(A) ampere (B) volt (C) watt (D) coulomb

(2) What number of electrons will be there in 1.6 C charge ?

(A) 10^{17} (B) 10^{18} (C) 10^{19} (D) 10^{20}

(3) $1\mu A$ = ---------- mA.

(A) 10^{-16} (B) 10^{-3} (C) 10^{3} (D) 10^{6}

(4) Which of the following materials has more number of free electrons ?

(A) Copper (B) Glass (C) Rubber (D) Iron

(5) According to Ohm's law,

(A) The resistance increases with the increase in current.

(B) The resistance increases with the increase in voltage.

(C) The current increases with the increase in voltage.

(D) The resistance and current both increase with the increase in voltage.

(6) The formula for an electric current is --------.

(A) $I = Q\ t$ (B) $I = \frac{Q}{t}$ (C) $I = \frac{t}{Q}$ (D) $I = Wt$

(7) The amount of 2 A electric current is passed for 1 minute through one conducting wire. How much total electric charge will pass through this wire ?

(A) 2 C (B) 30 C (C) 60 C (D) 120 C

(8) In an electrical appliance, the electric current of 4.8 A is passed, then the number of electrons passing through it in one second will be -----------

(A) 0.33×10^{19} (B) 3.3×10^{19} (C) 3×10^{19} (D) 4.8×10^{19}

(9) Which of the following formula represents the voltage ?

(A) $\frac{\text{Work}}{\text{Current} \times \text{Time}}$ (B) $\frac{\text{Work} \times \text{Time}}{\text{Current}}$

(C) Work × electric charge (D) Work × electric charge × time

(10) The unit of electric potential difference is --------

(A) J (B) J/C (C) J C (D) C/J

(11) If the work is to be done to take 3 C electric charge from one point to another point is 15 J, what will be the potential difference between these two points ?

(A) 3 V (B) 15 V (C) 5 V (D) 45 V

(12) The resistance of one conducting wire is 10 Ω. How much electric current will flow by connecting it with a battery of 1.5 V ?

(A) 0.15 mA (B) 1.5 mA (C) 15 mA (D) 150 mA

(13) On which factors does the resistivity of conducting wire depend ?

(A) Length of wire (B) Area of cross-section of wire

(C) Volume of wire (D) Material of wire.

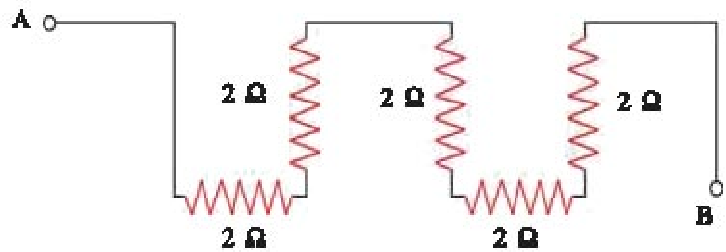
(14) If the five equal pieces of a resistance wire having 5 Ω resistance each is connected in parallel, then their equivalent resistance will be ––––

(A) 1/5 Ω (B) 1 Ω (C) 5 Ω (D) 25 Ω

(15) The unit of resistivity of the material is –––––.

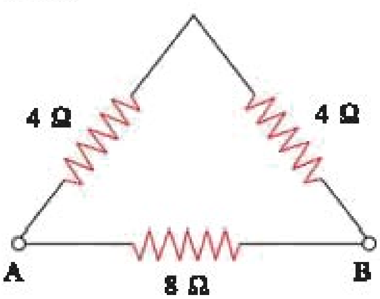
(A) Ω (B) Ω m (C) Ω/m (D) m/Ω

(16) What will be the equivalent resistance between points A and B of the following electric circuit ?



(A) 1 Ω (B) 2 Ω (C) 5 Ω (D) 10 Ω

(17) What will be the equivalent resistance between points A and B of the following electric circuit ?



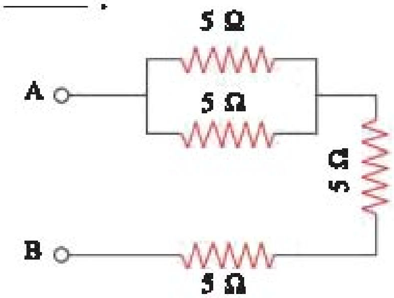
(A) 4 Ω

(B) 8 Ω

(C) 2 Ω

(D) 16 Ω

(18) The equivalent resistance between points A and B in the following electric circuit is ––––– .



(A) 2.5 Ω

(B) 5 Ω

(C) 12.5 Ω

(D) 20 Ω

(19) Which physical quantity has a unit of kWh ?

(A) Work (B) Electric power

(C) Electric current (D) Electric potential.

(20) 1kWh = ------------- joule

(A) 3.6×10^6 (B) 3.6×10^3 (C) 3.6×10^{-6} (D) 3.6×10^{-3}

(21) An electric heater consumes 1.1 kW power when 220 V voltage applied to it. How much current will be flowing through it ?

(A) 1.1 A (B) 2.2 A (C) 4 A (D) 5 A

(22) What makes the electric current flow through electric solution ?

(A) Only free electrons (B) Only positive ions.

(C) Only negative ions (D) Positive and negative ions.

(23) The distilled water acts as ------ for the electricity.

(A) Conductor (B) Insulator (C) Semiconductor (D) None.

2. Answer the following questions in brief.

1. What is an electric charge ? Give its types and write its unit.
2. What is a free electron ? Explain conducting and non-conducting materials in terms of it.
3. Give the definition of an electric current and define its unit.
4. Give advantages and disadvantages of series and parellel connection of resistors.
5. Write Faraday's laws of electrolysis.

3. Write the answers of following questions :

1. What is an electric potential ? Give the definition and unit of electric potential.
2. Explain the series connection of resistors and derive the formula of equivalent resistance.
3. Explain the parallel connection of resistance and derive the formula of equivalent resistance.
4. Explain electrical energy and derive its formula.

4. Answer the following questions in detail :

1. Draw the figure of voltaic cell and explain its construction. Explain flow of current in conductor through this cell.
2. What is electrolyte ? Describe the experiment showing flow of current in electrolyte.

5. Answer the following questions pointwise :

1. Write Ohm's law. Describe the experiment showing Ohm's law and write its conclusions.
2. What is electroplating ? Explain it with example.

6. Solve the following examples :

1. If 400 mA current flows through the bulb for 1 minute, how many electrons will pass through it ? (Ans : 15×10^{19} electrons)

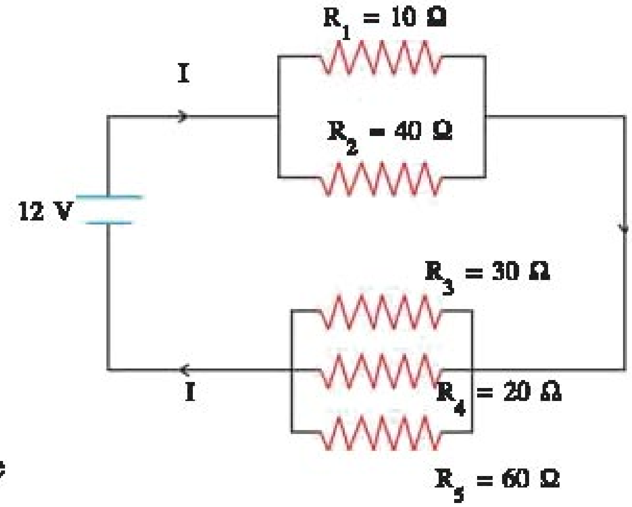
2. The 1800 C electric charge is passing through an electic bulb in one hour. How much current will pass through an electric bulb ? (Ans : 0.5 A)

3. The three resistors of resistance 5 Ω, 10 Ω and 30 Ω are connected with a 12 V battery in parallel. Determine (a) total current in the circuit (b) equivalent circuit resistance.

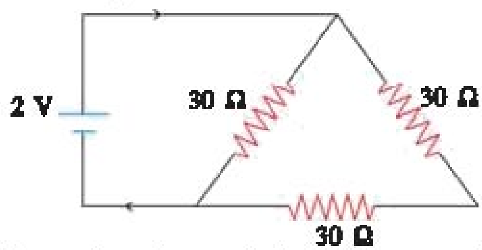
(Ans : I = 4 A, R = 3 Ω)

4. As shown in the figure the resitance are connected with a 12 V battery. Determine (a) Equivalent curcuit resistance (b) Current flowing through the circuit.

(Ans : (a) R = 18 Ω (b) I = 0.66 A)

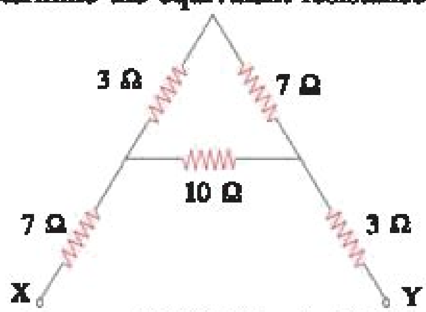


5. Find the electric current in the following circuit :



(Ans : 0.1 A)

6. Determine the equivalent resistance between points X and Y in the following circuit.



(Ans : 15 Ω)

7. Two lamps of 100 W and 60 W are joined in parallel with 220 V line. How much current will flow through the circuit ? (Ans : 0.73 A)

8. An electric heater consumes 4.4 kW power when connected with a 220 V line voltage then,

(i) Calculate the current passing through the heater.

(ii) Calculate resistance of a heater.

(iii) Calculate the energy consumed in 2 hours.

(Ans : (i) 20 A (2) 11Ω (3) 3.168×10^7 W)

UNIT

5

MAGNETIC EFFECTS OF ELECTRIC CURRENT

5.1 Introduction

In the earlier chapter, we have studied the heating and chemical effects of an electric current. In the present chapter, we shall study the magnetic effect of an electric current.

During 1819-20, a science teacher H.C. Oerstead discovered that the magnetic field is produced by an electric current in opposite to that the scientists named Michael Faraday, Andre Ampere etc. had produced an electric current from the magnetic field. It was proved from many experiments that electricity and magnetism are associated with each other. This branch of physics that covers universal study of electricity and magnetism is called electromagnetic or electrodynamics. The electromagnetic principles are widely used in loud speaker, electric motor, magnetic train (maglev), hard disk of computer, communication etc.

In the present chapter, we shall study the characteristics of magnetic field produced by electric current carrying conducting wire, coil, solenoid and the Faraday's experiments induced by magnetic field. In addition, we shall obtain the primary idea about electric motor and electric generator based on the principle of magnetism.

5.2 Magnetic Field and Magnetic Field Lines

Students, you have seen a bar magnet in the laboratory. You have studied about it in the Standard 8.

A bar magnet has two magnetic poles : (1) North pole (N) and (2) South pole (S). When a bar magnet is suspended freely through the string, the pole which becomes steady toward the north pole of an earth is called north pole (N) of a magnet and the other pole is called south pole (S). A repulsive force is resulted on bringing N-N or S-S poles of two different magnets nearer to each other while the attractive force is produced on bringing N-S poles. Magnetism of magnets is maximum at their poles. The magnetic force is represented by a magnetic field.

A magnetic needle experiences deflection when it is placed in the region near a bar magnet. Thus, a magnetic force experienced around the region of a magnet is called a magnetic field of a magnet. The magnetic field lines can be drawn to describe or to study this magnetic field.

The magnetic field lines are the pictorial representation of a magnetic field.

At first, we shall see how the field lines of a bar magnet can be drawn with the help of the following activity.

Activity :1

- For this activity, you need a bar magnet, magnetic needle, a white paper, a drawing board and a pencil.

(1) Place the white paper on a drawing board, then put the magnet in centre and mark its position with pencil.

(2) Now, place a magnetic needle near the north pole of a magnet. You will see that its south pole will be in the direction of magnetic north pole and the north pole of magnetic needle will be in the outward direction from the magnet. Mark the position of these two ends of magnetic needle with the pencil. In Figure 5.1 points A and B indicate the position of south and north pole respectively.

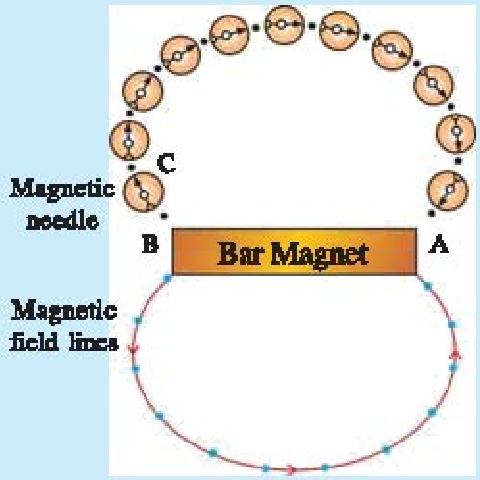


Fig. 5.1 Draw the magnetic field lines

(3) Now arrange the magnetic needle such that the south pole of needle is arranged on point B. In this position, mark the position (Point C) of north pole of magnetic needle.

(4) Thus, mark the positions of north pole of magnetic needle up to south pole of magnet by arranging it at the positions one after the other.

(5) Now draw a curve joining all of these points. This curve shows a magnetic field lines of a magnet. Draw magnetic field lines by placing a magnetic needle at different possible positions. This magnetic field lines show a magnetic field around the magnet.

The magnetic field lines for a bar magnet are shown in Figure 5.2

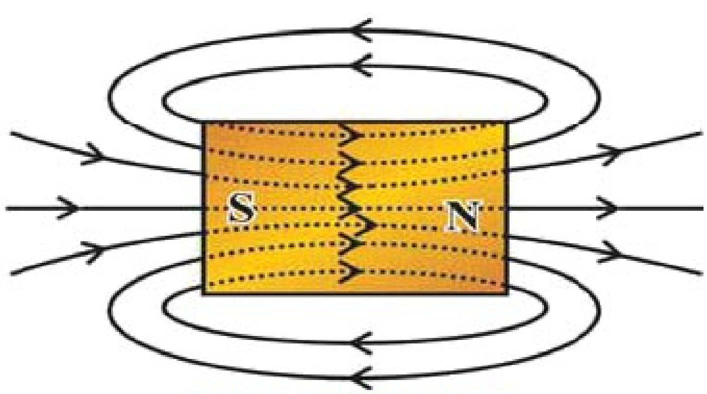


Fig. 5.2 Magnetic field lines of Bar magnet

Now let us see some characteristics of these magnetic field lines :

(1) The magnetic field lines of a magnet start from the north pole (N) and reach to the south pole (S) and these lines are in the direction from south pole (S) to the north pole (N) inside the magnet. Thus, they form close loops.

(2) The region in which the field lines are at close distance to each other has a strong magnetic field and if the field lines are at far distance from each other, the region has a weak magnetic field. Near the poles of a magnet the field lines are at close distance from each other so there is a strong magnetic field.

(3) The magnetic field is a vector quantity. So it has a magnitude and a direction both. The tangent drawn at any point of a magnetic field line (that means the direction of magnetic needle at that point) shows the direction of magnetic field at that point.

(4) Magnetic field lines do not intersect each other.

5.3 Magnetic Field Due to a Current Carrying Straight Conductor

In 1819, a science teacher H.C. Oerstead in a school in Denmark investigated that when an electric current is passed through the conducting wire, a magnetic field is produced in a region around it. We shall obtain its explanation through an activity.

Activity : 2

As shown in Figure 5.3 (a), connect a straight conducting copper wire in series with a battery and a key. Arrange a magnetic needle on a copper wire and arrange the wire such that it remains parallel to the magnetic needle.

Now make the electric current to flow through the wire by closing a key in the circuit and observe the magnetic needle. You will see the deflection in a magnetic needle (Figure 5.3 (b). On reversing the polarity of a battery in the circuit, the current will flow through the wire in a reverse direction, magnetic needle will also move in the opposite direction.

From this activity, we can say that, on passing the electric current through the wire it acts as a magnet and it possesses its own magnetic field so that the magnetic needle gets deflected. On reversing the direction of electric current, the direction of magnetic field is also reversed.

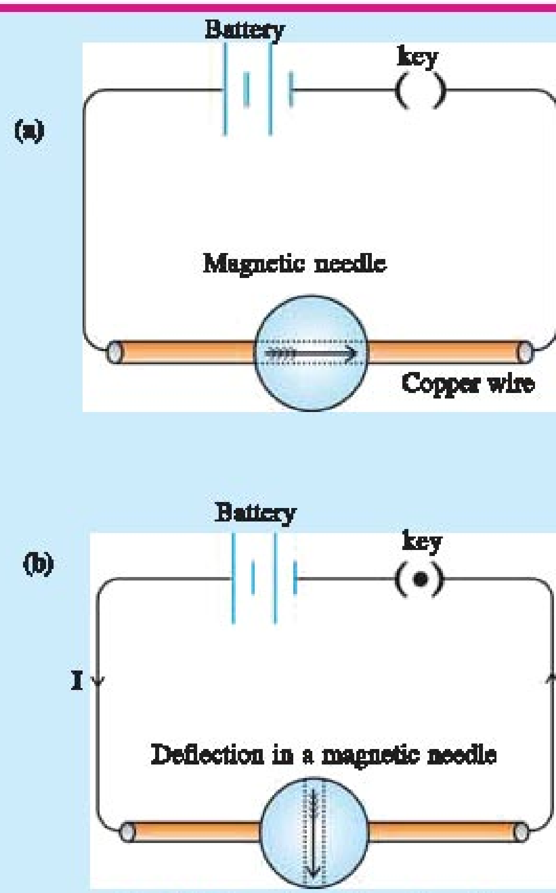


Fig. 5.3 Magnetic field produced by conducting wire

To understand the characteristics of magnetic field and the field lines of current carrying conductor perform the following activity :

Activity : 3

Make a hole in the center of a cardboard and pass the conducting wire through it. Connect a battery and key in series with this conducting wire. Spread the iron filings uniformly on the cardboard around the conducting wire.

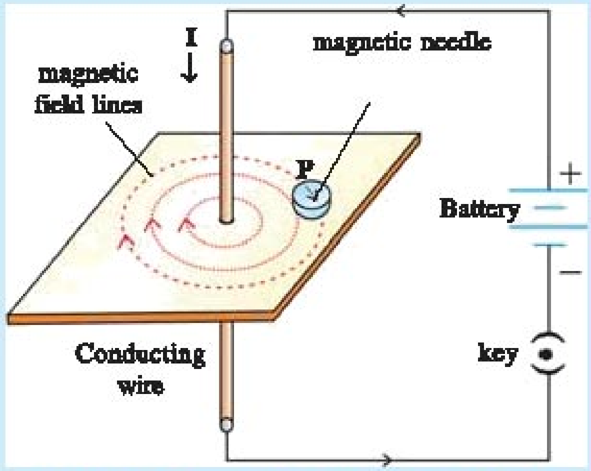


Fig. 5.4 Field lines of magnetic field produced by a conducting wire

Now, pass an electric current through wire by placing the key such that cardboard remains steady and tap the board two to three times. Look at the cardboard that what is the effect of an electric current on iron filings. You will see that the iron filings will get arranged in a concentric circular shape around a conducting wire. This circular pattern represents a magnetic field resulting from an electric current through the wire.

To know the direction of this magnetic field, place a magnetic needle near some point P. The direction in which a north pole of magnetic needle (arrow) points indicates the direction of magnetic field at that point.

Now on reversing the direction of an electric current you will see that the direction of needle placed at point P also get reversed.

The magnetic field produced due to the current flowing through the conducting wire is directly proportional to electric current through the conducting wire (Magnetic field α electric current). The field lines of this magnet are arranged circularly around the conducting wire in a plane perpendicular to an electric current. A magnetic field decreases inversely at a distance while moving away from the conducting wire. (Magnetic field $\alpha \frac{1}{\text{distance}}$)

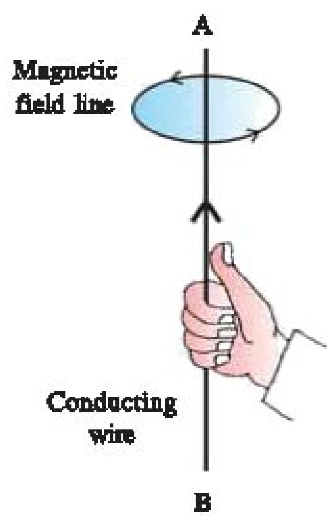


Fig. 5.5 Right hand thumb rule

Right hand thumb rule :

To known the direction of magnetic field produced by a current passing through any conductor, the right hand thumb rule is used.

Hold the wire in right hand (such that you do not get shock due to electric current !) such that the thumb pointing along the direction of current and the fingers are wraped on wire. In this situation, the magnetic field lines are such that the fingers wrap on wire as to forming the circular closed loops. (Figure 5.5)

5.4. Magnetic Field Produced by a Current Carrying Coil

We have seen that the magnetic field is produced while passing an electric current through a straight wire. If a wire is bent circularly and electric current is passed through it, the magnetic effect of current increases.

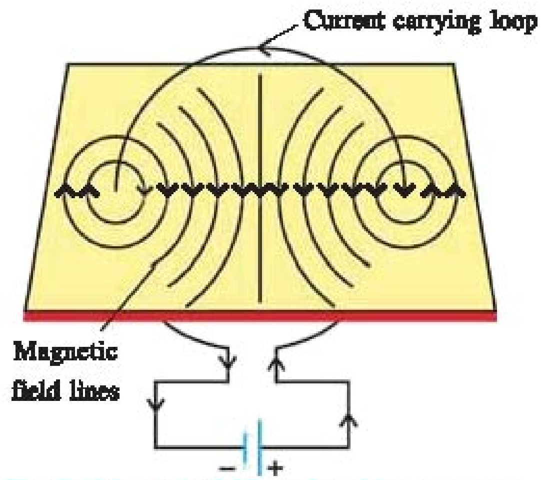


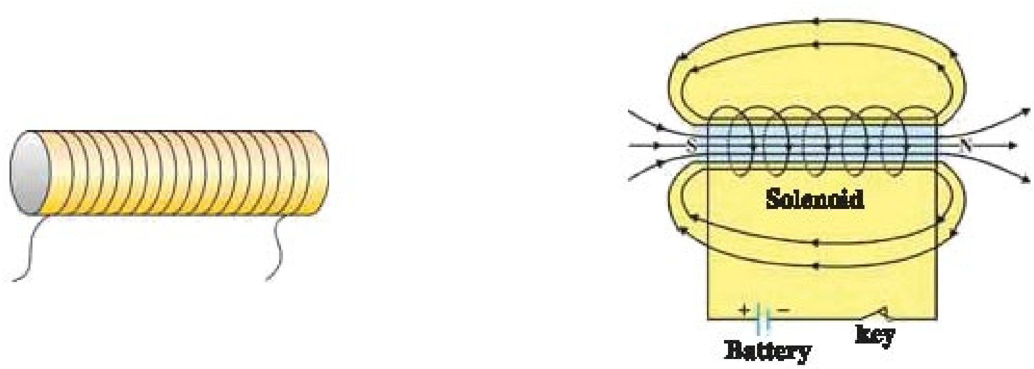
Fig. 5.6 Magnetic field produced in a current carrying ring (loop)

In Figure 5.6, the magnetic field produced by passing the current through a circular ring (loop) is shown. The field lines are circular near the wire of a ring. These circles get enlarged. While moving away from the wire, these circles near the center of ring (loop) turn into straight lines. Near the center of a ring, the field lines are at a close distance, so the magnetic field is stronger at the center. The direction of magnetic field is determined by a right hand thumb rule. The magnetic field at the centre of loop is linearly proportional to the electric current passing through the ring and inversely proportional to the radius of ring.

If a ring is made up of closely spaced N turns, the magnetic field at the center of ring will be N times stronger.

5.5 Solenoid

When an insulated straight conducting wire is bent into a coil (loop) having N turns, an arrangement like hollow cylinder is formed. **A construction like a coil made by a conducting wire wound closely and separately in a form of cylinder is called a solenoid.** In a Figure 5.7 (a) one such solenoid is shown.



(a) Solenoid (b) Magnetic field of a solenoid

Fig. 5.7 Solenoid and its magnetic field

As shown in Figure 5.7 (b), passing an electric current through a solenoid, an electric current will flow in the same direction through N turns of a coil.

The magnetic field resulting per each turn will add on as the direction of an electric current in each turn will be the same. As solenoid has N turns, the magnetic field resulting by it is N times stronger than the magnetic field resulting by each circular coil. The magnetic field lines resulting by a solenoid are shown by Figure 5.7 (b). It can be understood by comparing Figure 5.2 and Figure 5.7(b) that the magnetic field of a solenoid is just like a magnetic field of a bar magnet. Thus, one end of a solenoid behave like a north pole and the other end like a south pole. In the inner region of a solenoid the field lines are parallel that means the magnetic field is uniform at every point inside the solenoid. This magnetic field is directly proportional to the number of turns wound in a solenoid as well as it is directly proportional to the current passing through it.

By placing an iron like metal (e.g. large iron nails) inside the solenoid, its magnetic field becomes stronger. On passing the current through a solenoid, it behaves as a temporary magnet. Such magnets are called 'electromagnets.' Electromagnets are used in crane to lift the heavy objects (e.g. car).

5.6 Force on a Current Carrying Wire Placed in a Magnetic Field

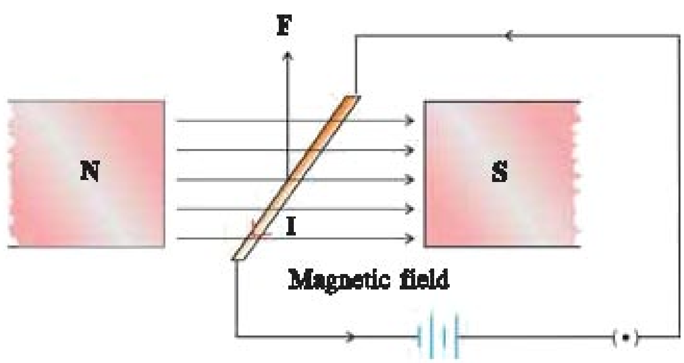


Fig. 5.8 Force acting on current carrying wire

Within a few days after the repetition of observations recorded by Oersted, a scientist, Ampere made another observation. He observed that the force is exerted on a current carrying wire placed in a strong magnetic field.

As shown in Figure 5.8, place a conducting wire in a strong stationary magnetic field.

Arrange a linear light conducting wire in a magnetic field perpendicular to it after tying it with a rigid base on both the ends. Now pass the electric current through the wire. You will see that the wire bends upwards. On reversing the polarity of battery and by flowing the current in the oppisite direction, the wire bends downwards.

When the electric current flows through the wire, a magnetic field is produced around it. During the interaction between the magnetic field of this wire and the magnetic field of a strong magnet, the wire and the magnet exert the force of equal magnitude on each other in the mutual and opposite direction. Here, the magnet is stationary and heavy so that it does not move, but the wire bends upwards as it is light in weight.

The magnetic force acting on a conducting wire is proportional to the electric current, magnetic field of a magnet and the length of a wire remain in the magnetic field. When the direction of an electric current through the conductor is perpendicular to the direction of magnetic field, maximum force is exerted on wire. The direction of this force is always perpendicular to the direction of an electric current and that of a magnetic field. When the direction of an electric current is in the direction of magnetic field or in the opposite direction, the force does not exert on a wire. The direction of magnetic force can be understood from Fleming's left hand rule.

Fleming's left hand rule :

Arrange the left hand such that the forefinger, the center finger and thumb remain at right angle to one another. Arrange the forefinger pointing in the direction of magnetic field and the center finger in the direction of an electric current, the direction of thumb gives the direction of magnetic force. (Figure 5.9).

Friends, now decide the direction of magnetic force acting on a wire shown in the above experiment.

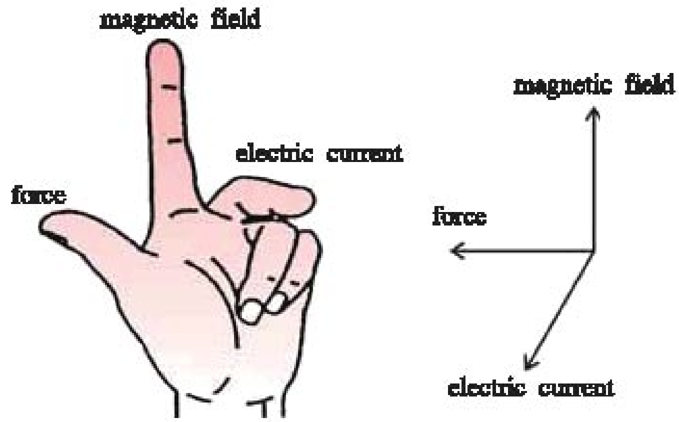


Fig. 5.9 Fleming's left hand rule

5.7 Electric Motor

An electric motor is a device that converts electrical energy into mechanical energy. The force acts on a current carrying wire placed in a magnetic field. The electric motor works on this principle.

The construction of an electric motor is as shown in Figure 5.10.

A loop ABCD of an insulated copper wire is placed in a permanent magnetic field such that AB and CD remain perpendicular to the magnetic field. The ends of this wire are connected to the two semicircular rings P and Q. The inner part of both the rings is insulated. Both the rings are arranged on an axle such that they can rotate easily on it. The outer position of the ring is in contact with a stationary brush X and Y. (In actual motor, a loop containing many turns is arranged on axis. This arrangement is called an armature).

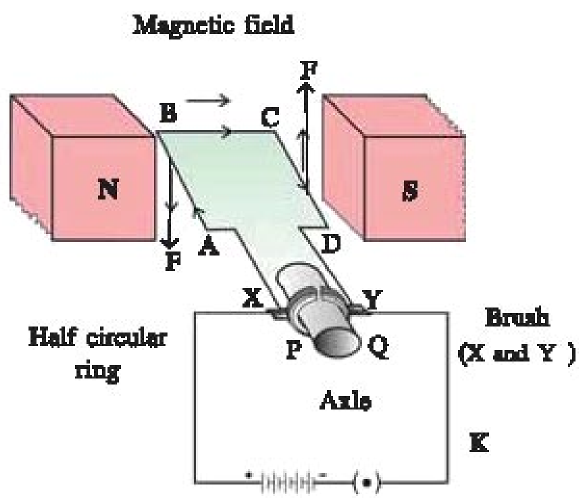


Fig. 5.10 Construction of an electric motor

The electric current flows through a loop ABCD by connecting a battery between the brushes X and Y. The current flowing through BC and AD is either parallel or antiparallel to magnetic field, so force does not act on them. But the currents flowing in wires AB and CD are perpendicular to the magnetic field, henec force acts on them. The direction of this force is obtained from Fleming's left hand rule. As shown in Figure 5.10, the force on AB acts in the downward direction and the force on CD acts in upward direction. As these two forces are in the mutual opposite directions, the loop ABCD is rotated.

After the completion of half rotation, the ring Q comes in contact with the brush X and the ring P with the brush Y, so that the direction of an electric current gets reversed. Due to this, the direction of force acting on AB and CD is also reversed. As a result, the loop continues to rotate in the same direction. At the end of one rotation loop comes to the earlier position. Thus, after every half rotation the direction of an electric current in a loop changes and loop rotates continuously.

The electric motor is used in the appliances like electric fan, mixer, washing machine, CD/DVD player etc. Make a list of other electrical appliances where an electric motor is used.

5.8 Electromgnetic Induction

We have seen that a magnetic field can be produced on passing the current through a conducting wire, circular ring and solenoid. Then is it possible to obtain electric current from the magnetic field ? A British scientist Michael Faraday, in 1831, gave the answer to this question. He had shown that how an electric current can be obtained with the help of a magnetic field through many experiments and from that gave principle 'of electromagnetic induction'. To understand this principle consider the following activity.

Activity: 4

- As shown in Figure 5.11, make a circular loop of a conducting wire and connect a galvanometer with it to record the presence of an electric current.

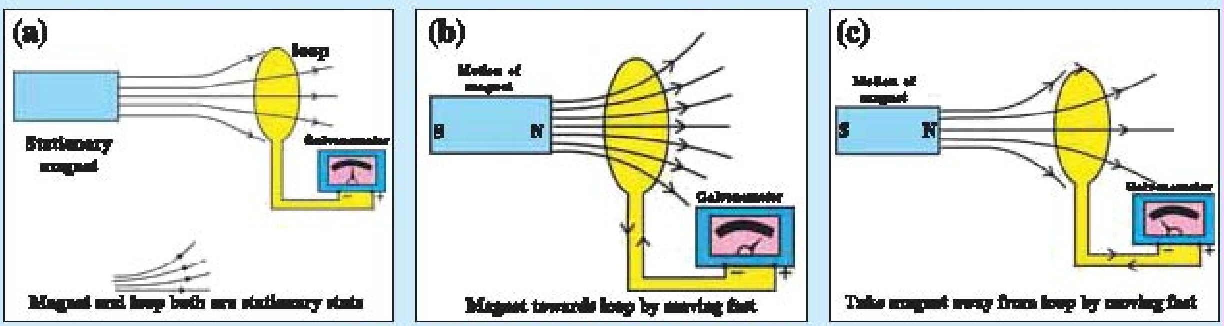


Fig. 5.11 Induce electric current in a loop

(i) Take a bar magnet and keep it stationary near the loop. You will see that the galvanometer does not show any deflection, (Figure 5.11 (a)).

(ii) Now move the N pole of a magent rapidly towards the loop and see that the galvanometer indicates the deflection on one side, which shows the presence of an electric current (Figure 5.11 (b)).

(ii) Now take the magnet away from the loop rapidly. Here the galvanometer will show the deflection in the opposite direction (Figure 5.11 (C)). This also indicates the presence of an electric current.

(iv) In the same way by taking S pole of a magnet the deflection in the galvanometer will be opposite to both the cases mentioned above.

(v) Above observation can also be verified by moving a loop instead of magnet. From this experiment it is so concluded that if the magnet and loop are moved relatively, an electric current flows in a circuit. This electric current is not produced by any battery, but it is induced by the motion of a magnet. Such an electric current is called **'induced electric current.'**

This phenomenon is known as an electromagnetic induction.

Because of the change in rate of change of number of magnetic field lines linked with the loop during the motion of magnet (or loop), an electromotive force (that means electrical potential difference) induces due to which the induced current is obtained in a loop.

If the speed of magnet is more, the change in rate of number of magnetic field lines will be increased and a large amount of induced current will be obtained. If the magnet becomes stationary, the change in number of field lines will be zero and the induced current will not be obtained.

The induced electromotive force resulting in loop or (induced electric current) is proportional to the change in rate of number of magnetic field lines and the number of turns of a loop.

In the phenomenon of an electromagnetic induction, the induced electric current is obtained only when a conductor moves in a magnetic field or the magnetic field around the conductor is changed. Normally, induced electric current can be obtained easily by moving a conductor in magnetic field. When the motion of conductor is in a direction perpendicular to the magnetic field, the large induced electric current is obtained.

The direction of an electric current is decided from the direction of a magnetic field and the direction of motion of a conductor. For this, Fleming's right hand rule is useful.

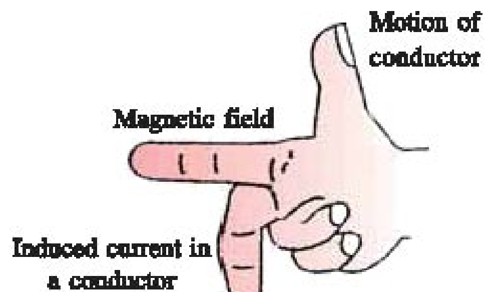


Fig. 5.12 Fleming's right hand rule

Fleming's right hand rule :

Arrange the forefinger, centre finger and thumb of a right hand at right angle to one another. Adjust a forefinger in the direction of magnetic field, and thumb pointing in the direction of motion of conductor. The direction of center finger indicates the direction of an induced electric current.

5.9 Electric Generator

We have seen that an electric current in the circuit can be obtained by the magnetic field. The electricity used in our house is also produced in this way. The device through which an electricity can be produced is known as an **electric generator. Electric generator converts mechanical energy into electrical energy. It works on the principle of an electromagnetic induction.**

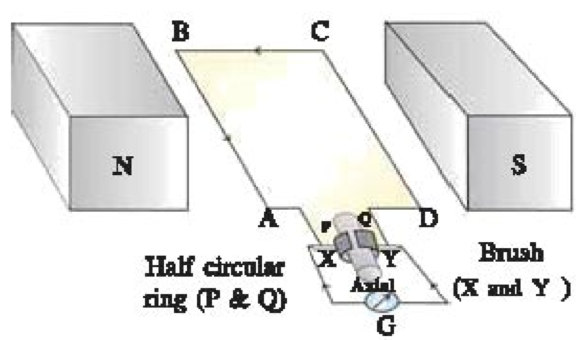


Fig. 5.13 Construction of an electric generator

The construction of an electric generator is like the construction of an electric motor which is shown in Figure 5.13. The two ends of a loop ABCD rotating in a magnetic field are connected with two semi-circular rings P and Q. These two rings are insulated from each other. These rings can slide while remaining in contact with the brushes X and Y. A galvanometer is connected between the two ends of brush. By applying mechanical rotation to the loop ABCD in the magnetic field, the number of magnetic field lines associated with it changes so that an electric current is induced which is observed from the deflection of galvanometer. Thus, the mechanical energy is converted into electrical energy.

By rotating the loop in a magnetic field, the side AB moves upward and the side CD moves downwards. The direction of an induced electric current in wire AB and CD can be known by Fleming's right hand rule. As shown in the Figure 5.13, induced electric current flows in a path B-A-G-D-C.

After the half rotation of a loop, the ring P comes in the contact with brush Y and the ring Q with the brush X. Here, the brush X is always in contact with the side moving upwards while the brush Y is always with the side moving downwards as a result of which the current flows only in one direction. This current is called direct or DC current. This type of generator is called DC generator. Similarly instead of half ring if full ring is used then A.C. current can be generated and such generator is called A.C. generator.

In practice, electric generator has a coil with many turns instead of loop. In the electric generator, to rotate coil, different types of energies are used, e.g. in wind mill, the electricity is produced by rotating its coil through wind energy. If the coil is rotated by using a flow or the fall of water stored in a dam, the electrical energy in large amount can be obtained. In generators used in hospital or theatre the coil is rotated with the help of a diesel engine and the necessary electricity is obtained during emergency.

5.10 Electric Bell

The electric bell works on the principle of an elecromagnet. Electric bell is made up of an electromagnet, bell (metallic cup), a soft iron strip and a contact screw. Bell is a cup shaped device made up of a metal. A soft iron strip works as a small hammer. The construction of an electric bell is shown in Figure 5.14.

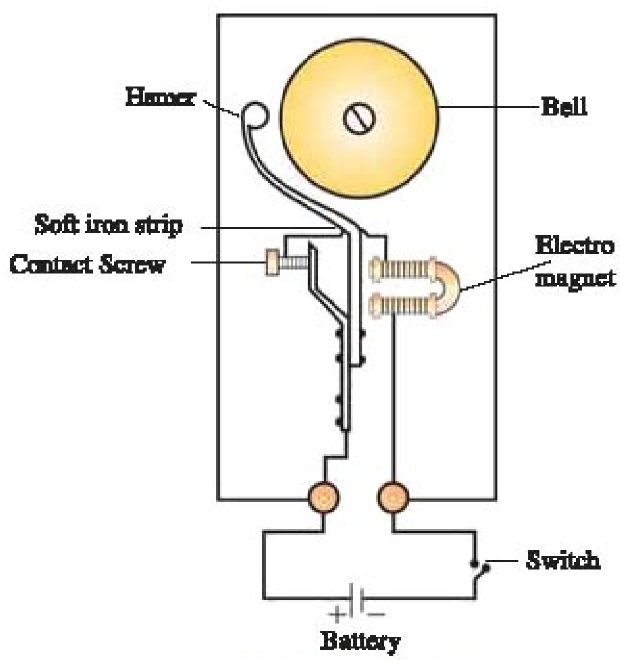


Fig. 5.14 Electric bell

When the circuit is switched on, an electric current returns in the battery after passing through an electromagnet, a soft iron strip and a contact screw. While passing a current through an electromagent acts as a magnet and attracts an iron strip. As iron strip (hammer) being elastic, it strikes with the bell. Simultaneously its contact with a contact screw is broken and current flows through electro-magnet stops. The iron strip comes in contact with the screw by obtaining an original position and again the electric current passes through an electromagnet.

This phenomenon occurs many times in a second and a hammer strikes many times with the bell, as a result the bell rings. The bell rings till the circuit is switched off.

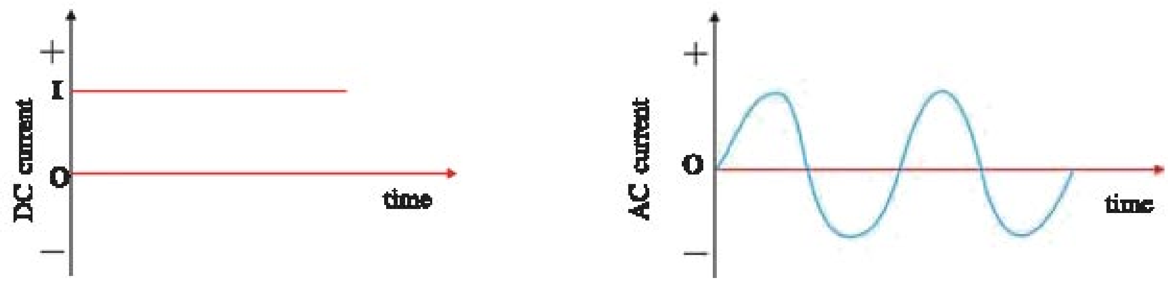
Electric bell is used in school, home, telephone, security system, fire alarm etc.

5.11 : DC Current and AC Current

The electric currents are of two types :

(1) Direct current or DC and (2) Alternating current or AC.

We use two types of electric appliances for domestic purpose. In some appliances, we use battery e.g. radio, cell phone, watch, laptop etc. The current obtained from the battery is direct current in which the current flows from the positive terminal to negative terminal of battery through an appliance. That means it flows only in one direction. The magnitude of this current remains constant with time and its direction also does not change (Fig. 5.15 (a)) DC current is also produced by DC generator.



(a) DC current (b) AC current

Fig. 5.15 DC and AC current

Another type of appliances such as refrigerator, mixer, electric iron, fan etc. work on AC current. In order to obtain the AC current, AC generator is used. AC voltages and currents are changed from positive to negative and negative to positive with time. In a house the electricity which we use, the direction of an AC voltage current changes 100 times in one second. So its frequency is 50 Hz.

The main advantage of using AC voltage or current is that it can be transmitted over long distance without much loss of electrical energy. While the generation of DC voltage is comparatively more costly. (Ask the price of 1.5 V battery in market).

5.12 : Domestic Electric Circuits

The electricity is generated in a power station. From the power station, this electricity reaches to our house through thick underground copper cables or through the overhead electric-poles. In the following Figure 5.16 how this electricity reaches to every place in the house is shown.

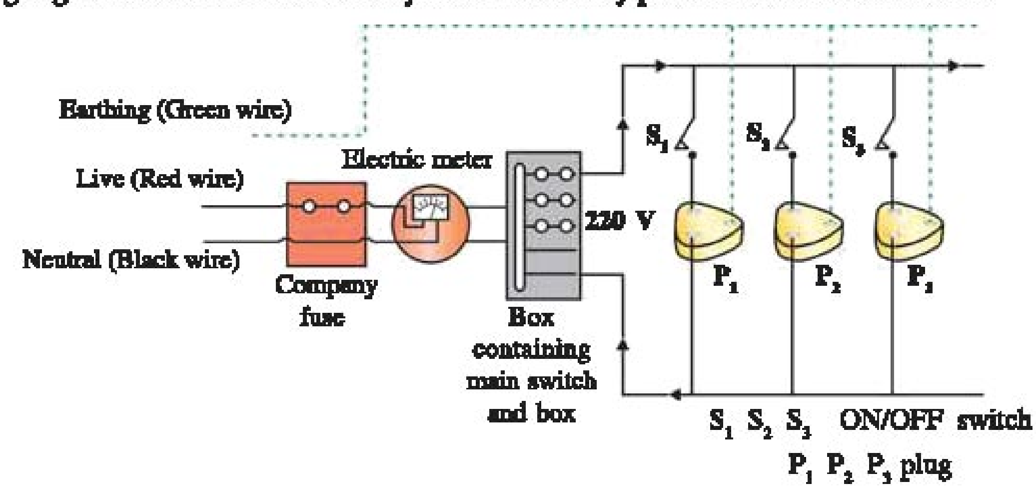


Fig. 5.16 Domestic electric circuit

One of the red coloured insulated wire brought to our house is known as live (positive) wire. Another black coloured insulated wire is known as neutral (negative) wire. The potential difference between these two wires is about 220 V. The current flowing in wire is AC whose frequency is 50 Hz. (In other countries like America this voltage is 110 V with 60 Hz frequency).

In the meterboard in the house, these wires pass into electric meter through main fuse. In the main switch board the fuses are kept for different circuits as per requirement. Through the main switch they are connected to line wired in house.

These wires carry two different values of current in the house. (1) 15 A current line is connected to the appliances of higher power ratings e.g. air conditioning machine, geaser, heater etc. (2) 5 A current line is connected to low power rating, e.g. tubelight, T.V., bulb, etc.

The third green coloured insulated wire is called **earthing wire**. This wire is connected with a metal plate and dumped near the house. Whenever there is a leakage of current in the appliances such as electric iron, toaster, table fan etc., it reaches to metallic surface due to which there is a danger for getting a shock. This earthing wire is connected with the metallic surface of such appliances so that the leaked out current goes directly to the ground through the earthing wire and electric shock can be avoided. In a house, every electric appliance is connected in parallel.

5.13 : Safety Measures in the Use of Electricity

The electricity is a form of energy. Therefore, many precautions are necessary while using the electricity. After knowing the various uses of an electrical energy, let us discuss what kind of precautions should be taken while using the electricity. We know that an electrical shock and fire are the main accidents caused by electricity.

Sometimes short circuit occurs in an electrical circuit. Short circuit means when positive and negative wires are connected with each other accidentally. If the insulating layer of wires or appliance in the circuit is defective, then short circuit may occur. In this circumstances, the total resistance of circuit suddenly decreases and an excessive electric current flows according to Ohm's law, which results in lots of heat and a spark is produced at a point of short circuit. Therefore, there is a possibility of a fire. (Sometimes overloading may also lead to the increase in current).

To prevent this a fuse is constructed. You have learnt somewhat about a fuse in the earlier chapter while studying heating effect of an electric current. Let us understand the construction of a fuse which is shown in the following Figure 5.17.

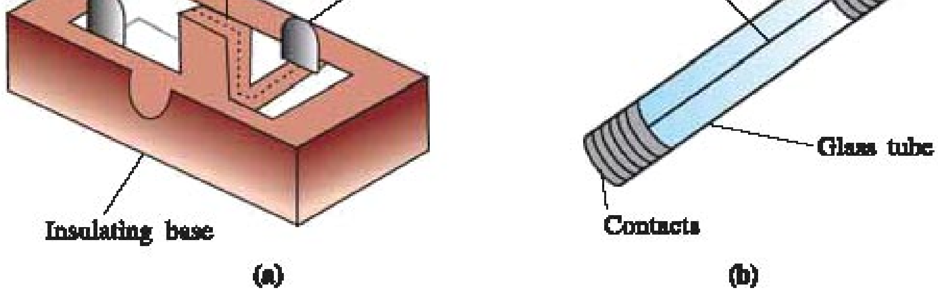


Fig. 5.17 Fuse construction

A conducting wire having a low melting point is connected with the metallic contacts on an insulator base. In Figure 5.17 (b) a fuse wire in a small glass tube connected with metallic contacts is shown. Such small fuses are used in the domestic appliances such as T.V., refrigerator. Due to some reason if current increases in the circuit, the fuse wire burn off immediately due to the heat produced and the electric current stops to flow, and major damage can be prevented.

Many types of fuse wires are available. The fuse wires are prepared from a pure tin or an alloy of lead and tin. Apart from this, while using appliances with large power consumption, a three-pin plug is employed. The third pin indicates earthing with the help of which we can prevent an electric shock.

What have you learnt ?

- **Magnetic field and magnetic field lines :** A magnetic field is around the region of a magnet. This magnetic field is shown by magnetic field lines. In the region outside the magnet, the magnetic field lines are pointing north pole (N) towards the south pole (S) and they form close loops. A magnetic needle placed any point of these field lines indicates the direction of magnetic field. Magnetic field lines never intersect with each other.
- **Magnetic field of a current carrying straight conducting wire :** The concentric magnetic field is produced around a linear conducting wire while passing on electric current through it. This magnetic field is directly proportional to electric current and inversly proportional to the distance from a wire.
- **A magnetic field of a current carrying circular ring (coil or loop) :** A magnetic field produced near a wire in a circular ring is concentric circular shaped. Near the center of a coil, these circles turn into straight lines. The magnetic field produced at the centre of a coil is directly proportional to an electric current and inversely proportional to radius.
- **Solenoid :** A coil like construction in a cylindrical form wound closely and separately from a conducting wire is called solenoid. Its magnetic field is like the magnetic field of a bar magnet.
- **Force acting on a current carrying wire :** While placing a current currying wire in a magnetic field, a magnetic force is exerted on it. This force is perpendicular to a magnetic field. The magnitude of this force is proportional to an electric current. If the conducting wire is parallel to the magnetic field, the force does not act on it. The force acting on the wire is determined by Fleming's left hand rule.
- **Electric motor converts electrical energy into mechanical energy :** While placing a conducting wire loop in a magnetic field, an equal but opposite magnetic force on its opposite sides acts as a result of which it rotates.
- **Electromagnetic induction :** Due to the relative motion between the loop and magnet, the number of magnetic field lines linked with the loop are changed. Therefore, an electromotive force is induced in the loop due to which an induced electric current is obtained in a coil. This is known as an electromagnetic induction. The direction of an induced current is determind by Fleming's right hand rule.
- **Electric generator :** The mechanical energy is converted into electrical energy with this instrument. The electric motor works on the principle of an electromagnetic induction.

- **AC and DC current :** The current which does not change with time and flow only in one direction (from positive to negative) is called undirectional current or DC current.

  The current whose direction is regularly changed from positive to negative, and from negative to positive is called an alternating current or AC current. In our house, we use 220V. AC voltage having frquancy of 50 Hz.

EXERCISE

1. Select the proper choice from the given multipule choices :

1. The direction of magnetic field lines in a region outside the bar magnet are ——————
   (A) From the N pole towards the S pole of a magnet.
   (B) From the S pole towards the N pole of a magnet.
   (C) In the direction coming out from both the poles of magnet.
   (D) In the direction entering in both the poles of magnet.
2. Which of the following statements is false ?
   (A) The direction of magnetic field line is from N to S.
   (B) In the region where the magnetic filed lines are at a close distance form each other, there will be a strong magnetic field.
   (C) The magnetic field lines form close loops.
   (D) The magnetic field lines can cross each other.
3. By which instrument the presence of magnetic field can be determined ?
   (A) Voltmeter (B) Ammeter
   (C) Galvanometer (D) Magnetic needle.
4. Who had first obseved the magnetic effect of an electric current ?
   (A) Faraday (B) Oersted (C) Volta (D) Ampere.
5. With the help of which law the direction of a magnetic field can be decided ?
   (A) Faraday's law (B) Fleming's right hand rule.
   (C) Right hand thumb rule (D) Fleming's left hand rule.
6. According to right hand thumb rule, whose direction is indicated by a thumb ?
   (A) Electric current (B) Magnetic field.
   (C) Magnetic force (D) Motion of a conductor.
7. The magnetic field produced in a straight conducting wire on passing the current through it is ——————
   (A) in the direction of current. (B) in the direction opposite to the current.
   (C) circular around the wire. (D) in the direction parallel to the wire.
8. What is the field line of a magnetic field passing through the centre of current carrying circular ring ?
   (A) Circular (B) Straight line
   (C) Ellipse (D) Magnetic field is zero at center.

9. Whose magnetic field is like a magnetic field of a bar magnet ?
   (A) Current carrying wire (B) Current carrying ring.
   (C) Current carrying solenoid (D) Current carrying rectangular loop
10. Who gave the principle of electromagnetic induction ?
   (A) Faraday (B) Oersted (C) Ampere (D) Volta.
11. Which is the direction of magnetic force acting on a current carrying wire placed in a magnetic field ?
   (A) along magnetic field (B) along the electric current.
   (C) perpendicular to magnetic field (D) opposite to magnetic field.
12. How is a current carrying wire placed in a magnetic field so that magnetic field does not act on it ?
   (A) Parallel to magnetic field (B) Perpendiculr to magnetic field.
   (C) At an angle 40° with magnetic field (D) Can be arranged any way.
13. From which of the following cases, the induced current in the loop will not be obtained ?
   (A) The loop is moved in the direction of the magnet.
   (B) The magnet is moved in the direction of the loop.
   (C) The loop and magnet are moved in the opposite directions with the same speed.
   (D) The loop and magnet are moved in one direction with the same speed.
14. Which instrument is used in converting electrical energy into mechanical energy ?
   (A) Electric generator (B) Electric motor.
   (C) Electric iron (D) Electric oven.
15. On which principle does the electric generator work ?
   (A) Electrical energy is converted into mechanical energy.
   (B) Electrical energy is converted into thermal energy.
   (C) Mechanical energy is converted into electrical energy.
   (D) Electrical energy is converted into light energy.
16. The magnitude of an AC voltage used in India is ———— and the frequancy is ———
   (A) 110V, 60Hz (B) 110V, 50 Hz (C) 220V, 50Hz (D) 220V, 60 Hz
17. Which coloured wire is used for earthing ?
   (A) Red (B) Black (C) Green (D) can be of any colour.
18. Which type of current is obtained from a battery ?
   (A) DC current (B) AC current.
   (C) Current of AC and DC both (D) Depends upon type of battery.
19. Which instrument is used to know the presence of an electric current ?
   (A) Fuse (B) Galvanometer
   (C) Voltmeter (D) Magnetic needle
20. A fuse wire is ——————
   (A) conductor (B) insulator
   (C) semiconductor (D) made up of any meterial.

21. ________________ rule is used to know the direction of an induced current in the circuit.

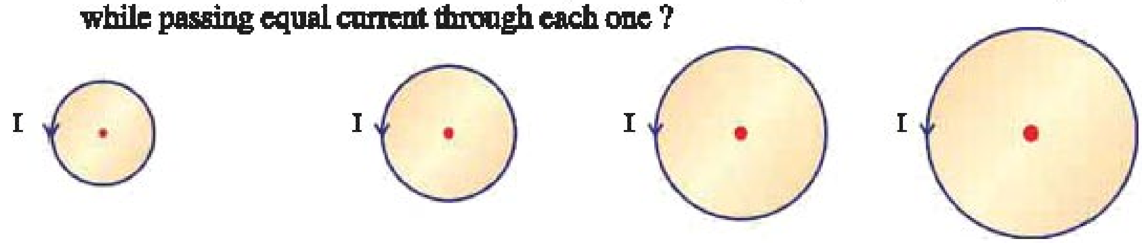
(A) Fleming's left hand (B) Fleming's right hand.

(C) Right hand thumb (D) Ampre's

22. How many times does an AC electric current with the frequency 50Hz change its direction ?

(A) 25 (B) 50 (C) 100 (D) 200

23. At the center of which of the following four circular rings has maximum magnetic field while passing equal current through each one ?



(A) (B) (C) (D)

2. **Answer the following questions in brief :**

1. Give the characteristics of magnetic field lines.
2. Explain the 'right hand thumb rule' to know the direction of magnetic field.
3. What will happen while placing a current carrying conductor in a magnetic field ? Explain.
4. By which law can the direction of an induced electric current can be determined ? Give the explanation of that law.
5. Explain the provision of an earthing wire.
6. Mention the usefulness of a fuse in a domestic electrical circuit.

3. **Write Answers of the following questions :**

1. Discuss the magnetic field resulting from a current carrying circular ring.
2. What is a solenoid ? Give the charcteristics of magnetic field resulting from solenoid.
3. What precautions should be taken during the use of electricity ?

4. **Answer the following questions in pointwise :**

1. Describe the experiment that explains the phenomenon of an electromagnetic induction and give its conclusions.
2. Write a short note on electric bell.
3. Describe domestic electric circuit with the help of a diagram..

5. **Answer the following questions in detail :**

1. Describe the principle, construction and working of an electric motor along with a figure.
2. Describe the principle, construction and working of an electric generator with a figure.

UNIT

6

UNIVERSE

6.1 Introduction

Man's curiosity to know the mysteries of the universe is as old as human civilization, and seems to be of undiminishing interest. The movement and the behavior of the heavenly bodies have always fasenated us. Scientific and technological developments try to resolve many questions regarding our understanding of the universe; many more have been emmerging while conflicting some of the conventional beliefs! With an intension to provide a scientific platform to explore the universe, we shall study the developments in space research, different tools to study them and, in particular, our solar system in detail. Brief outline of the space science program in India is also included.

6.2 Space Research : An Overview

Early scientific observations for space exploration is traced back to 17^{th} century when Galileo with his telescope could discover the four large moons of Jupiter and confirmed the different phases of Venus. In fact, till 1940s, almost all the information about the universe and solar system were derived from the observations made by such optical telescopes. Since optical telescopes have certain limitations, huge radio telescopes were later invented and installed. They provided us more accurate information about the celestial objects. They are usually located at higher altitudes far from population to avoid electromagnetic interference from radio, TV, radar, etc.. They are superior to the optical telescopes, as they are not sensitive to optical (visible light) pollution. For example, the Hubble - space telescope provides great deal of informations using optical, ultraviolet and infrared waves.

In order to have deeper understanding of neutron star, black hole and supernova as a link to explore the existence of the universe. The scientists realized that they required X-ray telescope. In this view, the first imaging X-ray telescope 'Einstein' (HEAO - 2), was launched into orbit by NASA (National Aeronautics and Space Administration) in 1978. It was renamed and launched as 'Chandra' in 1999. The Chandra X-ray observatory sends X-ray pictures of the distant galaxies also.

6.3 Changing Views on the Universe

Early astronomers studied celestial phenomena through observations. Many astronomical happenings cannot be observed more than once in life and they cannot be reproduced in the laboratories. So their records had taken very long time to get finalized in the reported forms, and inferences drawn from these observations were mostly through intuitive philosophy. For instance, Greek astronomer Ptolemy thought that all celestial objects orbit round the earth. Earth, in the centre of the universe, does not move at all. This **'earth - centred'** or **'Geocentric'** models of Ptolemy was challenged by Polish mathematician and astronomer Nicholas Copernicus through his mathematical model. He suggested that all planets orbit round the sun including the earth, while moon revolves round the earth. The sun is in the centre of the universe and is stationary. Copernicus model is known as **'Sun-Centred'** or **'Heliocentric'** model. In common, both these models have assumed circular orbit for celestial objects. It is worth mentioning that, historically, Copernicus model was the first predictive geometrical model. This heliocentric notion of the universe was also supported by Galileo's telescopic observations.

In the sixteenth century, John Kepler, like Newton's laws of motion, discovered laws of planetary motion. He considered elliptical orbit to explain the motion of Mars. Later, it is realized that even within the solar system, the sun is not at the geometric centre of any of planet's orbit. It is rather at one of focii of the elliptical orbit. Over the course of 18th and 19th centuries, the status of the sun was confirmed as one star among many. In the beginning of 20th century, the picture of 'Akash Ganga' (Milky-way) galaxy became clear. It is proved that the sun is at a distance of 30,000 light years from the galactic centre.

For Information Only

Astronomers measure distance in Astronomical Units (AU). One AU is equal to the average distance between the centre of the earth and the sun.

i.e. $1 \text{ AU} = 149{,}598{,}000 \text{ km} \approx 1.496 \times 10^8 \text{ km}$

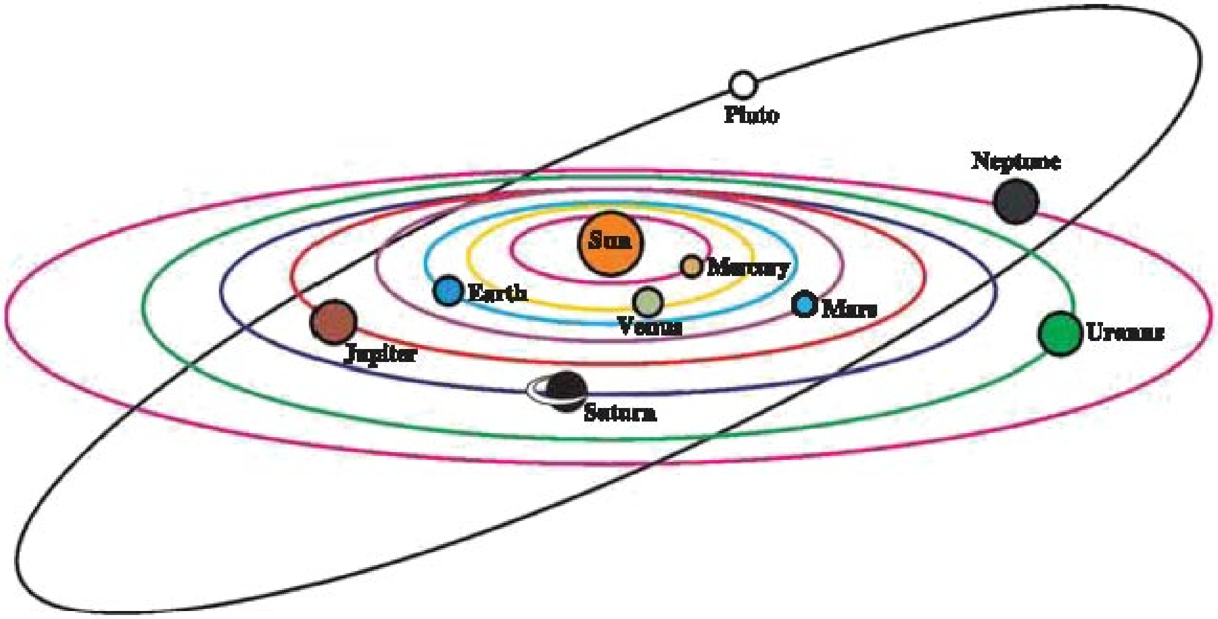
Another unit to measure celestial distances is light year.

$1 \text{ light year} = 9.46 \times 10^{12} \text{ km} = 63{,}240 \text{ AU}$

However, the **"principle of relativity"** given by Albert Einstein suggests that there is no obvious centre of the universe. Further, Hubble and X-ray telescopes have revealed the fact that the universe is expanding and stars and other heavenly bodies are receding away from each other. According to famous theoretical physicist, Stephn Hawking, there may be many more such universes !

6.4 Solar System

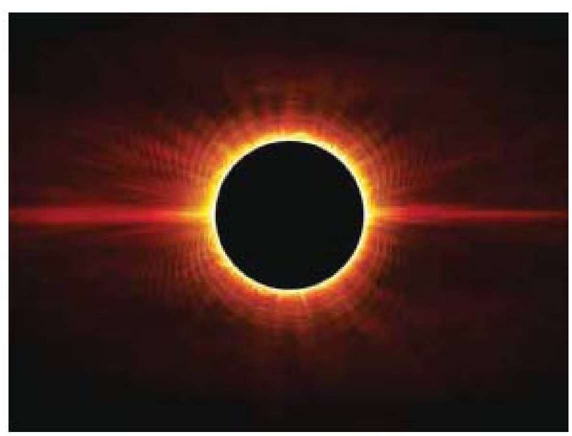
Formation and evolution of the solar system is estimated to have begun 4.568 billion years ago due to the gravitational collapse of a small part of a giant molecular cloud. Most of the collapsing mass assembled in the centre and the sun was formed. Therefore, the sun contains 99.86% mass of the solar family. Remaining mass was flattened into orbits and planets, moons (satellites), asteroids, meteors, comets, etc. were formed. In the Figure 6.1 orbits of nine planets are shown. However, Pluto is now considered as a dwarf planet. The centripetal force required to keep them in respective orbits is provided by the gravitational force between the sun and the planets.



6.1 Orbits of the planets in the solar system

The sun is the main source of energy for us. We receive just desired amount of energy, which keeps water in liquid state. This is essential for the origin and evolution of life on the earth. As the sun is essential for the existence of the solar system, we shall first study the sun.

(1) Sun : Its diameter is about 13,92,000 km. Temperature of the core region in the sun is about 1.5 crore K. Due to such high temperature matter in the core region is in the plasma state. Further, due to high density, pressure in the central part of the sun is also very high. These conditions are responsible for thermonuclear fusion of 4 hydrogen nucleii into a helium nucleus. During this process some mass of hydrogen nuclei is converted into energy as per the Einstein's mass-energy relation, $E = \Delta mc^2$, where c, is the speed of light in vacuum. This large amount of liberated energy is in fact the source of energy for us. This also gives self-luminous to the sun.



6.2 Corona

However, towards the surface its temperature reduces and is about 6000 K at the surface. Thus, sun looks like a sphere of hot gases. Matter (plasma) in the sun is confined by strong magnetic field surrounding it. Variation in magnetic field gives rise to sun spots. Number of sun spots keep on changing periodically with time. Its period is of 11 years.

About the 400 km thick, bright layer around the sun is known as 'photosphere'. The density of photosphere is very low as gases above the photosphere are very hot, hence this layer is seen only during the solar eclipse. It is known as 'Corona', meaning crown (Figure 6.2).

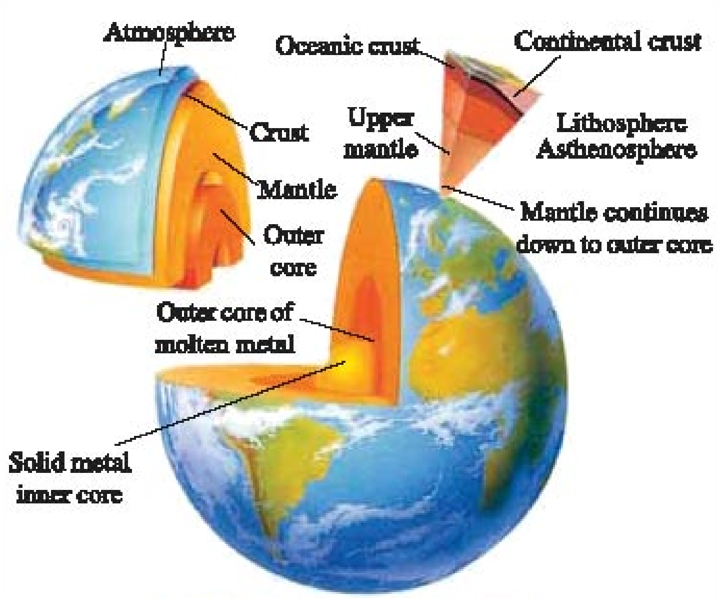
Currently, the sun is in its matured state. It is estimated that the sun will die in approximately 5 billion years. Before that it will expand in size and will become red-giant. Sun's planets may be carried away by nearly passing heavy celestial objects or they may be destroyed or ejected into the interstellar space.

(2) Terrestrial Planets : After the sun, other important members of the solar family are the planets. Our solar system has nine planets. They can be classified into two : (1) Planets which are found inside the orbit of Mars, known as terrestrial planets. (2) Planets which are found outside the orbit of Mars, known as jovian planets. Mercury, Venus, Earth and Mars are the terrestrial planets. Structure of these planets resemble to earth. These planets have fewer number of natural satellites and have thin atmosphere.

Mercury : **It is the smallest planet in the solar system.** Its mass is approximately $\frac{1}{18}$th mass of the earth. It contains metals like nickel (Ni) and iron (Fe) at the centre. Its outer surface is rocky. Strength of its gravitational force is approximately one third of the earth. Due to weak gravitational field and short distance from the sun, it has a very thin atmosphere containing vapours of potassium and sodium. As a result, difference between day and night temperatures is very large. Temperature of the side facing the sun is 427°C whereas night temperature is -173°C. Due to such extreme temperature difference life is not possible on mercury. Its surface has many craters. Some of them are volcanoes. Most of the craters were formed due to hitting of meteors. Mercury has no moon.

Venus : It is the second planet of the solar system and is the neighbour of the earth. It is the most bright planet. Its outer atmosphere consists of white clouds of carbon dioxide (CO_2). It is the only planet that is spinning from east to west, which is in the opposite direction to other planets. Due to this reason, **the sun rises in the west and sets in the east on the venus.** Its orbit is more circular. The surface of the venus contains large mountains, valleys and volcanoes. It also has no moon.

Earth : The third planet in the solar family is the earth. **This is the only planet in the solar family which supports life.** It has thin layer of atmosphere. Thickness of this layer is about 800 to 1000 km. Thanks to atmosphere that when meteorus strike the earth they burn due to friction and get converted into gaseous matter. Thus, atmosphere protects us from meteors. Moreover, it contains thin layer of ozone gas. This ozone layer absorbs ultraviolet rays of the sun and reduces



6.3 Internal structure of the earth

their harmful effects on the living organisms. Atmosphere produces green-house effect, which maintains suitable temperature necessary to sustain life. Due to such favourable circumstances, life has originated on the earth.

Outer layer of the earth is made up of mud or rocky stones (silicate). Here, proportion of silicon dioxide (SiO_2) is very large. Its core region contains semi-liquid made up of molten iron, magnesium and silicate like substances (Figure 6.3). It has one satellite, the moon (Chandra).

Mars : Mars is also our nighbouring planet away from the sun. It is reddish in colour. The surface of the mars has large valleys, mountains and dry rivers. It has negligible atmosphere (1% of the atmosphere of the earth). This atmosphere mainly contains carbon dioxide. It also contains nitrogen (N_2) and argon (Ar) in small amounts. **It is believed that its poles are covered by dry ice (solid CO_2).** Information available from Path Finder Mission of 1997 indicates existence of flowing water on the mars in the past. At present, probability of existence of life on the mars is negligible. It has two moons, namely Phobos and Demos.

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NASA of USA has launched a space vehicle known as Mars Reconnaissance Orbiter (MRO) for detailed study of the mars in August 2005. This un-manned vehicle landed on the mars on 10^{th} March 2006 after seven months journey. It sends informations and photographs regarding its atmosphere. NASA has taken up a mission to send a man on the Mars in next 10 years. Scientists of NASA are of the firm opinion that in the near future human beings will be sent to Mars.

(3) Jovian Planets : Planets of the solar system with their orbit outside the orbit of the Mars and composition similar to Jupiter are known as Jovian planets. These planets are bigger in size but with lesser density. They are mainly made up of Hydrogen, Ammonia and Helium. Rings are usually seen around them. They have moons of bigger in size.

Jupiter : Jupiter is the fifth planet in our solar system. It is a luminous planet. **It is the biggest planet in the solar system.** It is about 1400 times bigger than the earth. Bands of hazy brownish colour are present on the jupiter. Colour concentration of these bands changes continously. Due to its brightness, this planet can be seen with naked eye also. It has relatively rocky core and no real surface. Jupiter has more than 60 moons.

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Because of its mass, Jupiter has a strong gravitational field and due to this strong gravitational field comets passing near by it gets deviated. Sometimes they break up into pieces. The reason is very clear. The part of comet nearer to the jupiter experinces more gravitational force compared to the part of the comet away from the Jupiter. In 1994, comet Levy Shoemaker was broken into more than two pieces while passing by this planet. Some of the pieces fell on this planet also. Observations of the jupiter through radio telescope indicates that jupiter radiates two to three times more energy than the energy it receives from the sun. Possible reason behind this might be thermonuclear process taking place on a large scale at its core.

Saturn : Saturn is the second largest planet of the solar family. Its size is 850 times that of the earth. **Three beautiful luminous rings add to its beauty.** Some of the scientists believe that saturn is completely made up of hydrogen. Its core region is made up of solid hydrogen while its crust is made up of fluid hydrogen. While some other scientists argue that its core is made up of rocks and metals surrounded by thick layer of ice and atmosphere. Its surface temperature is very low. Its largest moon is Titan.

Uranus : Uranus was discovered by William Harshall in 1781. Its size is 64 times than the earth. Its diameter is 3.7 times larger than the earth. Its core contains iron, magnesium and silicate rocks. It has layers of hydrogen and helium surrounded by the clouds of methane and ammonia in the ice from. **This planet is surrounded by narrow rings of ash colour.**

Neptune : Neptune is bluish in colour. It has two luminous and two hazy rings. Thus, in total, it has four rings. Its core region is made up of silicate rocks and ice. Its upper crust contains rocks of methane, ammonia and water in the ice form. It is a very cold planet. Triton and Nerid are its well known moons.

Pluto : As per the new classification of the planets, pluto is known as a dwarf planet. It is very cold, dark and yellowish planet. Its surface density is similar to that of the earth. Therefore, it is also considered to be terrestrial planet. Its orbit is highly elliptical. Its core region has silicate rocks surrounded by water, methane and carbon monoxide in the solid form. Its outer most thin layer contains nitrogen, methane and carbon monoxide. Its atmosphere mainly consists of methane gas. **Pluto and its moon, Sheron form a binary system, and they revolve around their common centre of mass.**

Uranus, Neptune and Pluto cannot be seen with naked eye. Therefore in ancient days only 6 planets were known. Last three planets were discovered using telescope.

6.5 Asteroids

The rocks that failed to form a planet during the time of the formation of the solar system are known as asteroids. Majority of them are found in a belt lying between the Mars and Jupiter (Figur 6.4). Such rocks are of various sizes. They revolve around the sun. Number of asteroids are approximmately more than 1 lac out of which orbits of more than 4000 asteroids are now determined. Asteroids have irregular shapes. Size of these asteroids can be estimated on the basis of their luminosity. The first ever discovered and the largest asteroid is Ceres. Its diameter is approximately 1000 km. Luminous asteroid vesta is approximately 400 km.

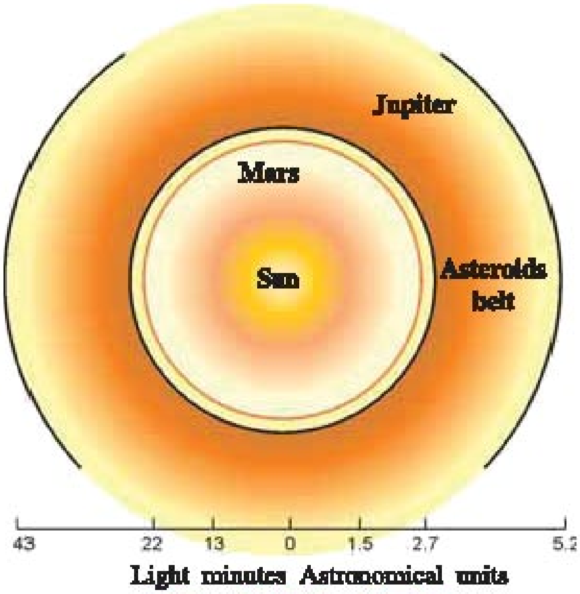

Figure 6.4 Asteroids belt

While revolving around the sun these asteroids keep colliding with each other and keep on breaking. Sometimes their debris come to the earth in the form of meteors. Some of them are very large, which are known as meteorites.

Asteroids are composed of silicon, nickel, chromium and calcium. Gold and platinum are also the probable coustituents.

6.6 Shooting Stars

Various substances of different sizes keep on coming to the earth regularly. Such substances are known as meteors. When they enter the earth's atmosphere, they burn due to friction cause by the earth's gravity and a streak of light is seen. This, in ordinary language, is called shooting star (Figure 6.5). In fact, they are not stars. Maximum number of meteors are seen in the period between August to November. Sometimes, the heavenly body of large size cannot burn completely and strike the earth surface as fire ball. Such burning fire balls are known as meteorites.

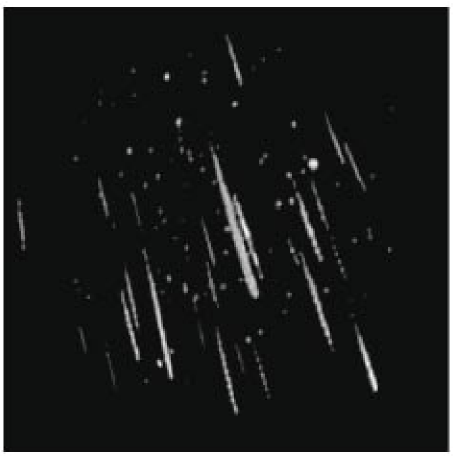

Fig. 6.5 (a) Shooting stars

Fig. 6.5 (b) Meteorite

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When very large meteorites strike the earth they create craters. Some of such craters are converted into lakes. Lonar lake of Maharashtra is the example of it. One such crater in Arizona in America is 180 m deep and 1300 m broad. The meteorite which produced this crater is believed to be having 10 lac ton mass. In 1976, near Dhajala village of Surendranagar district, a meteorite weighing 40 kg struck. This meteorite is known as Dhajala Ulka (Ulka means meteorite). Actual origin of these meteorits is unknown but they are suspected to be from the belt of the asteroids.

It is found that compositions of meteorites is largely due to sand, iron, nickel, etc. This gives an idea of what is the composition of other planets of the solar system. However, it is difficult to say with surety unless we know the exact origin of the meteorites.

In the desert of western Australia numerous meteorites are found. Here, an automatic station is established, which provides more informations about the origin of meteorites and locations of their landing.

6.7 Comets

Around the solar system far from Pluto there is a group of about 10 billion celestial objects, which are known as cloud of Urt. Due to gravitational force of the sun and other stars, they start moving towards the sun. They are known as comets. Most of the comets revolve around the sun in an elliptical orbit (See Figure 6.6). Comets are spheres of dust and icy rocks. As they come closer to the sun, ice vapourizes and a long bright tail is formed. When comet is nearest to the sun its luminous tail is the longest and points opposite to the sun. As it moves away from the sun, its tail becomes shorter and eventually vanishes.

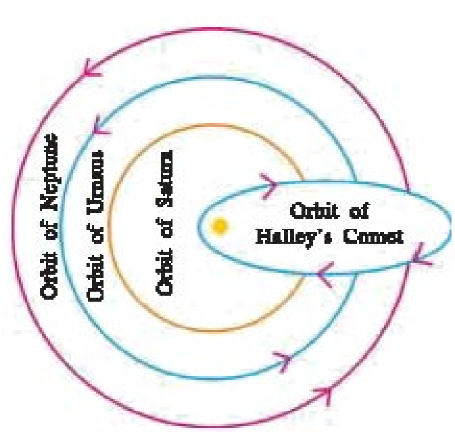


Fig. 6.6 Orbit of a Comet

Since tail is seen from the earth, comet is also called a tailed-star. In fact it is not a star and tail is not permanent.

Uptill now, orbits of 750 comets have been discovered. The most famous of them is Halley's comet. It comes close to the sun at every 76 years. It was last seen in 1986 and will be seen again in 2062. It is named after Edmond Halley, who studied it in detail.

In 1997, Helbopp, another brilliant comet, was seen for about 19 months with naked eye.

Comets are basically made up of water, carbon dioxide, ammonia and other frozen gases along with dust particles. Since their compositions resemble to the composition of the other members of the solar family, they are of great importance to scientists. Detailed study of their tail has shown that it contains the molecules of CO and HCN. These molecules are essential to form complicated compounds necessary for the origin of life. Hence, some of the scientists believe that such molecules must have arrived at the earth through comets, and life had originated on the earth.

In ancient days arrival of the comet was considered as the bad omen and was believed to be responsible for war, epidemic or natural calamity like flood. But modern science has proved that the arrival of a comet is just a normal event and there is no need to panic about it.

6.8 Stars

The celestial self luminous objects which produce energy on their own in the form of radiation due to thermonuclear fusion process are called stars. Stars are hot spheres of gases like hydrogen and helium. The sun is also one such star. There are numerous stars of various sizes. Stars bigger in size compared to the sun have carbon-nitrogen thermonuclear fusion process in their cores.

The stars seem to be permanent and of the same nature as if they do not undergo any changes. But they are born, grow and eventually die. Sun-like stars die as white dwarf while those much larger in size end up in black holes. Different phases of their life span depends on their sizes.

Stars appear in different colours. The star having red colour has the lowest surface temperature and the star having blue colour has the highest surface temperature. Colour and surface temperature depends on their phases. Their physical characteristics change with time.

6.9 Nakshatra

An imaginary sphere covering the sky with the earth at its centre is known as the celestial sphere. The ecliptic of the celestial sphere is divided into 27 equal parts, which are known as **Nakshatra.** Their angular region is $360° \div 27 = 13°20'$. (Read as thirteen degree twenty minutes.) Our moon undergoes 13°20' angular displacement every day along the elliptic path. Thus, moon remains in one nakshatra for a day, while the sun remains in one nakshtra for $365 \div 27 = 13.5$ days. Nakshatra are given names on the basis of imaginay figures formed by joining stars or by luminous stars belonging to the nakshatra. Pushya, Swati, Ardra, etc. are some of the well known nakshatras. In India, they have religious importance too.

6.10 Night-Sky

You might have noted that the star rises four minutes earlier compared to the previous day. It is because the earth takes 23 hours 56 minutes to complete one rotation about its own axis while day is made up of 24 hours. During these 4 minutes stars in the celestial sphere undergo angular displacement of 1°. In a month their angular displacement becomes 30°. If you watch them at particular time everyday, within six months they undergo angular displacement of 180° (i.e. from horizon to horizon). Thus, after the six months the same stars are not seen. This shows that night-sky changes everyday. But this change is not noticeable in a single day and one should observe the sky for considerable time like a month or so.

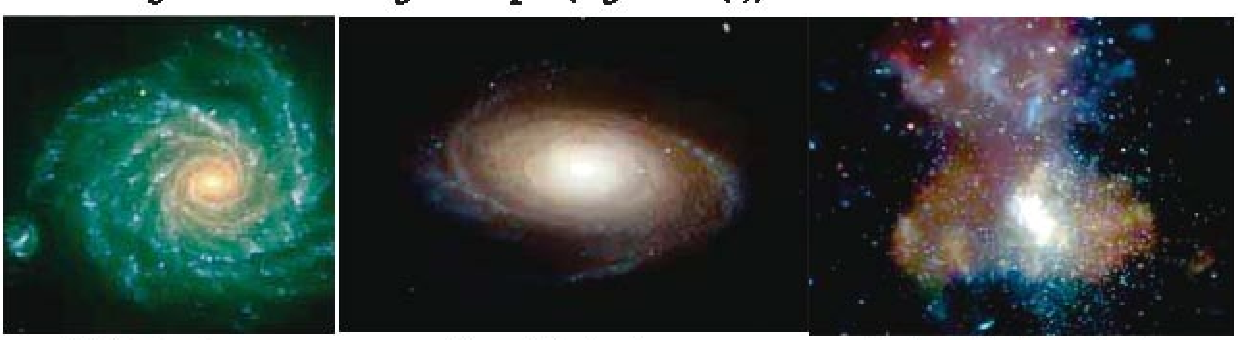
6.11 Milky-Way and Other Galaxies

Numerous stars in the universe are not distributed uniformly. But they are found in big clusters. Such a big cluster of stars is known as a galaxy. During dark and clear sky, we can see a milky belt stretching from north to south. It looks like flowing river Ganga, and hence the name Milky-way. If milky-way is viewed from the side, bulging is seen at the centre and tapered towards the ends. When it is viewed from the top it is seen spiral in shape. Its diameter is about 1 lac light years and the thickness of the middle part is about 15 to 20 thousand light years.

As already noted, our sun is at 30,000 light years away from the galactic center. It completes one revolution around the galactic centre in 22.5 crore years at the speed of 250 km per second. There are about 10^{11} galaxies and each galaxy contains about 10^{11} stars. Thus, in all there are about 10^{22} stars. Galaxies are of different shapes, of which following two are the main :

(1) Spiral galaxy (Figure 6.7 (a)) (2) Elliptical galaxy (Figure 6.7 (b))

Other galaxies are of irregular shapes (Figure 6.7 (c)).



(a) Spiral galaxy (b) Elliptical galaxy (c) Irregular Shaped galaxy

Fig. 6.7 Different types of Galxies

Most of the stars in elliptical galaxies are very old and red in colour. Whereas in spiral galaxies most of the stars are bluish and they are young. So it is believed that elliptical galaxies are older than spiral galaxies. In the universe, number of spiral galaxies are more.

6.12 Blackhole and Pulsar

Blackhole : A blackhole is a region of space from which nothing can escape. Gravitational collapse occurs when outward internal pressure is insufficient to resist the star's own gravity. When massive star (whose mass is larger compared to solar or sun's mass) at the end of its life cycle collapse in a supernova, and eventually ends up into a black hole. Once a black hole is formed it can continue to grow in mass by absorbing mass from its surroundings and may become supermassive black hole with millions of solar mass. It is believed that star formation in the young universe might have produced such massive blackholes of mass 1000 times greater than the solar mass. Such blackholes are found at the centers of most galaxies. There is a strong evidence of a blackhole of more than 4 million solar mass at the center of our Milky-way.

Around a blackhole, we may imagine a surface, called an "event horizon", which marks the points of no return. Light reaching to event horizon will be absorbed like a black body in thermodynamics, so it is called 'black'. However, quantum mechanics predicts that even black holes emit radiation at finite temperatures. Since temperature of a blackhole is inversely proportional to its mass, they radiate by small amount. This makes very difficult to observe this radiation, and astrophysicists have to rely on indirect observations. Its existence can sometimes be inferred by observing its gravitational interactions with its surrounings. For example, X-ray binaries (binary star which emits radiation in X-ray region of the electomagnetic spectrum) are formed due to accreating matter by one star (accreation-star) from the other (regular-star). By studying regular star we can determine the presense of the blackhole.

Classification of blackholes based on their mass, electric charge and angular momentum. However, still it is a mystery to astrophysicists that what mechanism is responsible for restricting gravitational collapsing to zero.

Prediction of neutron stars through Einstein's general theory of relativity sparked interest in such gravitationally collapsed objects. This was then supported by the discovery of rapidly rotating neutron stars, pulsar, in 1967.

Pulsar : The core of massive star when compressed during supernova becomes a neutron star. However, so formed neutron star retains its original angular motion. But due to its reduced size it rotates faster. This infalling matter and high speed rotation results into the emission of high energy radiation along its magnetic axis. Howerer, alignment of magnetic axis and rotation axis are generally not same. This misalignment causes the electromagnetic radiation to be seen twice during its one rotation. Thus, it appears as if the star radiates in pulsar. Hence the name is given pulsar. In fact, it is the abbreviation of a pulsating star. This process of pulsating energy stops after about 10-100 million years when pulsar stops rotating. To date, the slowest observed pulsar has period of 8 seconds.

6.13 History of Space Exploration

Space exploration is the term used to explore the outer space using the principles of space technology and astronomy. While the observation of objects in space is known as astronomy, it was the development of large rockets during the early 20th century that allowed physical space exploration to become a reality. The pioneer of space travel was a Russian, Konstantin Tsiolkowsky (1857-1935). He realized that only a rocket could take us to near space. He also proposed that a rocket should be built in stages so it would dump each stage when its fuel (propellant) would be exhausted. We know that rocket works on the Newton's third law of motion. Fuel in the rocket engine burns very quickly, thus producing large amount of gases. These gases come out of the nozzle with large momentum and rocket is pushed upwards. This action requires special kind of fuel. For example, a mixture of liquid hydrogen and oxygen is used as a liquid fuel, while powdered mixture of ammonium perchlorate or ammonium nitrate and aluminum are used as solid fuel. Rockets are disgined to carry scientific devices or instruments, which are called payloads.

A multistage rocket has two or more stages, each of which contains its own engines and fuels. The main advantage of multistage rockets and boosters is that once the fuel is exhausted, stages are dropped off to reduce the weight of the rocket. This provides more acceleration to the remaining assembly with less fuel requirement. Indeed, these multistage rockets have done tremendous jobs to push space exploration truly into the multifold discipline.

For example, the Russians have launched first artificial satellite, Sputnik-I on 4th October 1957. Immediately, America launched its first satellite Explorer-I in January 1958. The first human being, Yuri Gagarin, was sent in space by Russia on 12th April 1961, while the first space walk was done by Aleksi Leonov on 18th March 1965. In the subsequent years scientists launched series of satellites to investigate different planets and moon of a solar system. On 21th July 1969, astronaut Neil Armstrong of Apollo 11 mission landed and stepped on the moon. In 1971 and 1973, Russians and Americans launched their space stations, Salyut - I and Skylab, respectively. **In 1980, India has launched its first satellite, Rohini.**

In fact, after the first 20 years of space exploration, scientists of different countries have realized that space exploration is a very costly mission. Therefore, they have shifted focus from competition to cooperation, and have jointly built International Space Station (ISS). As a result, many more countries have participated in space exploration programme.

Multistage rockets have couple of major drawbacks (i) staging may result into failures like separation ignition or stage collision, and (ii) the cost factor. This led to the foundation of a reusable launch system – orbital space craft and the space shuttle. It carries different payloads to low earth orbit, provides crew rotation for ISS and performs servicing missions. It can also be used to recover satellites and other payloads from orbit to earth or it may repair the damage part in the orbit itself.

Space Shuttle :

The first space shuttle, Colombia, was launched on 12th April 1981, followed by Challenger, Discovery, Atlantis. Hubble telescope was launched from the space shuttle Discovery (Figure 6.8) in April 1990.

Space shuttle is composed of threee main parts : The reusuable Orbiter Vehicle (OV), the expandable external tank (ET), and the two reusable solid rocket boosters (SRBs). The space

6.8 Discovery Space Shuttle

shuttle is lanuched vertically like a conventional rocket, revolves around the earth, does its job and returns to earth, like an aeroplane. After which it is repolished for reuse. During the flight of space shuttle, the SRBs are dropped with the help of parachute to a predecided location in the ocean. During the descent the orbiter passes through different layers of atmosphere and slows down, primaily, by aerobraking. Howerer, speed of the space shuttle remain still so high that air-friction generates large heat energy. To protect against this heat, outer surface of the space shullte is made up of a special alloy. Once the space shuttle comes to very low altitudes, pilot takes over the control of space shuttle and it lands like an aeroplane.

All space shuttles are launched from Kennedy Space Centre due to favourable geographic conditions.

However, space shuttle flights are not always safe. On 28th January 1986, Challenger disintegrated just after its launch, and all the seven crew members died. On 1st February 2003, Colombia met an accident during its re-entry to the earth. Again all seven astronauts were killed including Kalpana Chawla of Indian origin.

Apart from physical space exploration to understand the nature and existence of the universe, scientists try to simulate conditions in the laboratories similar to the one which was supposed to be just after the big bang. For example, Large Hedron Collider (LHC) is the world's largest particle accelerator experiment. Scientists expect novel insight to understand deepest laws of nature, existence of dark matter, origin of universe, etc. from this experiment.

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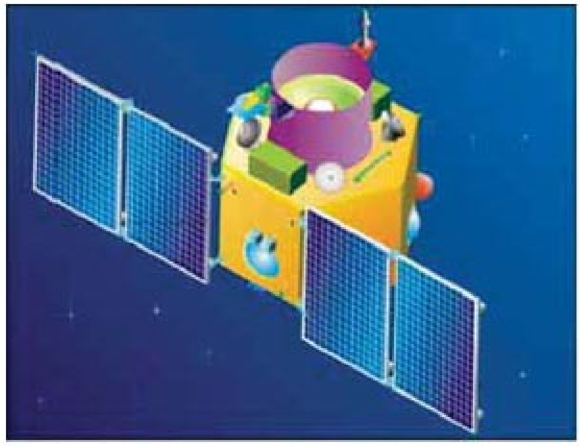
The LHC lies in a 27 km long circular tunnnel at a depth of 175 m at the Franco - Swiss border near Geneva. It is designed to collide opposing beams of very high energy protons. They are accelerated to almost the speed of light in vacuum. It is built by European Organization for Nuclear Research. Total cost of the experiment is expected to be approximately $ 4.4 billion !

The term hadron refers to particles composed of quarks. e.g, proton.

6.14 Various Types of Artificial Satellites and Their Orbits

A smaller heavenly object revolving around a bigger object is known as satellite. Moon is the natural satellite of the earth. "A man-made automatic system launched in the space with a special purpose and revolving around the earth is known as an artificial satellite."

Modern artificial satellite are equipped with transpondors, high resolution cameras, radio meters, solar panels and necessary fuels. These satellites receive signals from the earth-station and send observations taken by various equipments in a proper format to the earth station. India launched its first satellite Rohini on 18th July 1980 using SLV-3 rocket, and became the seventh nation in the space-club. So far, India has launched Rohini, SROSS, IRS series, Resource sat, Carto sat satellites (Figure 6.9) using our own rockets. We have also launched INSAT series with the help of other countries.



6.9 Cartosat Satellite

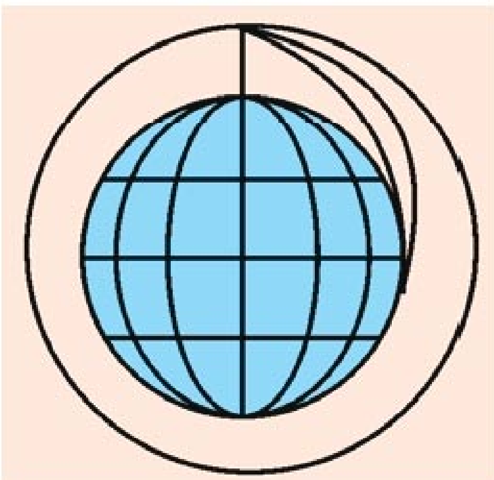


Fig. 6.10 Trajectory of projectile

To understand the principle of satellite launching we have to go back to gravitation. Suppose you throw a stone in the horizontal direction from the top of a tower, what do you observe ? You would observe that the path of the stone is perabolic and it returns to the earth. If the object is thrown with more speed, it travels longer distance in the horizontal direction. Gradually, if we increase the speed in this way then at some speed the object will start revolving around the earth instead of falling on the earth Figure 6.10. The minimum speed required is 8 km/sec. to revolve around the earth in orbit. Before projecting the satellite in this way it is taken to a height of 200 km to minimize the friction due to atmosphere.

Orbits of the Artificial Satellites :

Usually artificial satellites are kept in one of the following orbits :

(i) Equatorial orbit and (ii) Polar orbit.

"The orbit which is parallel to the equator is known as an equatorial orbit."

"The orbit which is parallel to meridian is known as a polar orbit." (Figure 6.11)

Fig. 6.11 Orbits of Artificial Satellites

The revolution period of a satellite having height from the earth's surface equal to 35,786 km is 24 hours. Therfore, such satellite is seen to be stationary when viewed from the earth. It is called geo-stationary satellite and such orbit is known as geo-stationary orbit. Satellites in such orbits do not require any energy for its revolution. By arranging three geo-stationary satellites at proper place in the orbit, the entire earth can be linked and signals from any corner of the earth can be sent to any other place on the earth.

Some of the satellites are launched in polar orbits. Their height from the surface of the earth is about 1000 km and their revolution period is 2 hours or less. Such satellites have a number of revolution around the earth in a day, and they pass through a location on the earth at a regular interval of time. This interval of time is called repeating time. Remote sensing satellites of India and America's landset visit any location on the earth at the interval of 21 days and 16 days, respectively. During these days they scan the entire earth.

Useful life time of the satellite depends on stability of their orbits. So their path is constantly observed and they are re-established in their orbit using rocket engines attached to them.

Orbits of artificial satellites like natural satellites are elliptical due to the effect of gravity. However, to calculate the revolution period orbits are considered circular for the sake of simplicity.

6.15 Uses of Artificial Satellites

Using artificial satellites we are able to see events happening in any corner of the world on our television. We also get weather forecast. In the field of education, country-wide classroom becomes the reality. Tele-conferencing enables us to have a meeting with people separated by long distances. Satellites are also useful in space research, communication, remote sensing, defence, etc. Human beings have lots of advantages due to satellites. Some of the uses are discussed below.

For Communication : In the field of communication, we use satellites for telecomunication, television transmission, radio networks and computer networks. Country-wide classroom and tele-conferencing have enabled us to spread education in remote villages of the country. For this purpose India has launched INSAT series. So far we have launched INSAT 1,2,3 series for these purposes.

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British scientist Arther Clark, in 1945, had suggested that a geo-stationary satellite can be used for communication purpose for microwave relays.

For Weather Forecast : We can also get information regarding weather using satellite of INSAT series. These satellites can take photographs of clouds, provide useful information about surface temperature of the oceans, temperature of various layers of atmosphere, humidity in the atmosphere, etc. They also provide forecast regarding monsoon or sudden climatic changes that can cause storms or hurricanes.

For Remote Sensing : "Remote sensing is the method by which information about a substance or a phenomenon can be obtained using scientific instruments without direct contact with them."

Using satellite we can carry out geological survey of metallic ores present in the earth's crust, changes in the forest and environment, water resources, agriculture resources, etc. It also provides information about diseases that can spread in the crops. It is also used in oceanography and study about movements of fishes. The installation of sensors in the remote sensing satellites covers the area of 10 sq. m to 6400 sq. m, and they send the information to the earth-station.

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Remote sensing techniqes basically depends on solar radiation and enerey. Each and every substance on the earth emits energy in certain amount depending on their temperature. They also reflect incident solar energy in various amounts. The sensors kept in the satellites receive these radiations and send its information to the earth-station. Study of such information enables us to interpret the situation of the surface of the earth. Of course, it requires special training to interpret these data or informations.

6.16 Indian Space Research Programme

Artificial satellites have potential applications in the field of mass communication, weather forecasting and remote sensing. ISRO (Indian Space Research Organigation) has developed and launched various satellites.

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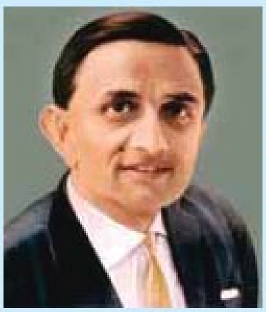


Dr. Vikram Ambalal Sarabhai (1919-1971) was born in Ahmedabad on August 12, 1919. He carried out his research on cosmic waves and obtained Ph.D. degree from the Cambridge University. He established 'Physical Research Laboratory' (PRL) and 'Ahmedabad Textile Industry Research Association' (ATIRA) in Ahmedabad. He has given valuable contributions in the development of rockets and space research in India. He is known as the Father of India's space programme. Scientists contributing remarkably in this field are given Dr. Vikram Sarabhai Memorial Prize.

They are widely used for tranamission of TV signal and communication, along with a geological survey for mineral resource, for agricultural purpose and study of marine life.

The rocket launching programme of ISRO have been utilized on commercial basis by other countries also.

6.17 Programmes Conducted by ISRO

- INSAT (Indian National Satellite System) has its series INSAT - 1, 2, 3 were launched in the space and INSAT - 4 was launched on 22nd December 2005 from Guana (France) which will be useful for Direct To Home (DTH) service for TV transmission.
- IRS (Indian Remote Sensing) satellites have been launched. IRS -1, IRS - P series which is meant for commercial purpose, whereas METSAT (Meteorological satellite) is used for weather forecasting.
- The Resource satellites are used for the study of oceanography.
- Carto sat is used for geographical survey.
- Rohini satellite series is for astronomical observations.
- PSLV (Ploar Satellite Launching Vehicles) is used for launching 1000-2000 kg class of remote sensing satellite.
- GSLV (Geo Synchronous Satellite Lauch Vehicle) launched 'EDUSAT' nearly weighing 2500 kg in space, in September 2004.

What have you learnt ?

- Limitations of optical telescopes have led foundation for X-ray telescopes. The 'Chandra' X-ray observatory takes X-ray pictures of astronomical happenings.
- Our views on the universe continuously change. From earh-centred to sun-centred, expansion of the universe, many universes, etc.
- Our solar system is made up of nine planets, satellites, asteroids, meteors, comets, etc.
- Planets which are found inside the orbit of Mars and having structure similar to the earth are known as **Terrestrial planets**.
- Planets which are found outside the orbit of Mars and having composition similar to Jupiter are known as **Jovian planets**.
- Venus is the only planet in the solar system, which revolves around the sun in opposite direction to other planets.
- Asteroids are the rocks that failed to form a planet. They are found between Mars and Jupiter.
- Asteroids keep on colliding with each other, and keep on breaking. Their debris coming to the earth are known as **meteors**. Meteors of large sizes are known as **meteorites**.
- Due to earth's atmosphere, meteors coming to earth burn and produce a streak of light. This appears as a shooting star.
- Comets are also known as tailed-star. Its tail is longest and point in opposite to the sun when it is nearest to the sun. They revolve round the sun at a regular interval of time.
- The celestial self luminous objects due to thermonuclear fusion are known as stars. Stars are not permanent. But they born, grow and eventually die.
- 27^{th} part of the ecliptic sphere is known as nakshatra.
- Stars are found in big clusters, known as galaxies. Our solar system belongs to Milky-way galaxy. There are about 10^{11} galaxies each containing 10^{11} stars. They are mainly found in two shapes : spiral and elliptical.
- Black holes are supermassive celestial objects such that no radiation can escape from their strong gravitational pull. Their existence, usually, can be found through X-ray binaries.
- Pulsating neutron stars are known as pulsar.
- Rockets require special kind of fuels (propellant)
  Liquid fuel : Liquid hydrogen and oxygen.
  Solid fuel : Mixture of ammonium perchlorate or ammonium nitrate and aluminum.
- Space exploration is now done using space shuttle. Important parts of it are Orbiter vehicle (OV), expandable external tank (ET) and solid recket boosters (SRB).
- Man-made satellites are known as artificial satellites. They are used for the benefit of the mankind. Geostationary satellites and polar satellites are the two types of artificial satellites.

EXERCISE

1. Select the proper choice from the given multipule choices :

(1) Which of the following is a star ?

(A) Sun (B) Phobos (C) Asteroids (D) Comet

(2) Which of the following is not a member of the solar system ?

(A) Asteroids (B) Shooting Star

(C) Sun (D) Artificial satellite

(3) What is the periodic time of Halley's comet ?

(A) 67 yrs (B) 76 yrs (C) 86 yrs (D) 100 yrs

(4) Matter in the core region of the sun is in .... state.

(A) Solid (B) Liquid (C) Gaseous (D) Plasma

(5) .... is the most brilliant planet of the solar system.

(A) Earth (B) Venus (C) Jupiter (D) Mars

(6) Poles of Mars are covered by ....

(A) dry-ice (B) water-ice (C) nitrogen (D) iron

(7) .... was the first person to land the moon.

(A) Yuri Gagarin (B) Aleksi Leonov

(C) Kalpana Chawla (D) Neil Armstrong.

(8) Distance of geostationary satellite from the earth's surface is .... km.

(A) 43,000 (B) 37, 956 (C) 35, 786 (D) 23, 123.

2. Answers the following questions in brief :

(1) Write the two uses of artificial satellites.

(2) What are stars and what are they made up of ?

(3) Give difference between earth-centred and sun-centred models.

(4) How X-ray astronomy is useful in space exploration ?

(5) Explain the formation of the solar system in brief.

(6) What are terrestrial planets ?

(7) What are jovian planets ?

(8) Explain equatorial and polar orbits of artificial satellites.

3. Write answers to the following questions :

(1) Write notes on :

(i) Mercury (ii) Venus (iii) Mars (iv) Saturn
(v) Pluto (vi) Shooting Stars (vii) Night-sky (viii) Milky-Way galaxy

(2) How artificial satellites are useful in communication ?

(3) What is remote sensing ? How satellites are useful in remote sensing ?

4. Answer the following questions in detail :

(1) Give a detailed note on the program conducted by ISRO.

(2) Write a note on the blackholes.

(3) Write a note on the Earth.

(4) Write a note on Nakshatra.

5. Answer the following questions pointwise :

(1) Write a detailed note on comets.

(2) What are galaxies ? Give detailed account of different types of galaxies.

(3) Write a note on Space shuttle.

UNIT

7

ACIDS, BASES AND SALTS

7.1 Introduction

From the studies in earlier standards, it can be said that juice of sour fruits, juice of lemon, solution of tamarind and butter milk, used in everyday life have acidic nature. Aqueous solutions of baking soda and washing soda have basic nature; while aqueous solution of common salt has neutral nature. The acidic, basic and salt nature of aqueous solutions is due to the acid, base or salt present in them. Thus, the utility of acid, base and salt is specific in our everyday life. The aqueous solutions of these salts are very important in biological systems and chemical industries. We shall obtain more information about acid, base and salt in this unit.

7.2 Theories of Acid and Base

What are acid and base ? Many scientists have proposed different theories for the answers to these questions. About 300 years ago, Robert Boyle defined acid and base on the basis of chemical properties. Acids are sour in taste, turn wet blue litmus paper into red and liberates dihydrogen gas (H_2) by reaction with metal; while bases are bitter in taste, turn wet red litmus paper into blue. By neutralisation reaction between acid and base, salt and water are produced. This type of definition is called operational definition because it is based on its properties. This definition is also called old definition. In the modern definitions of acid-base – Arrhenius, Bronsted - Lowry, Lewis acid-base theories are included. We shall understand the first two from them – Arrhenius and Bronsted-Lowry theories.

(1) Arrhenius Acid-Base Theory

The definite concept about acid and base was given in 1884, by Sweedish Scientist Svante Arrhenius. According to his opinion **"Acid is a substance containing hydrogen which produces hydrogen ion (H^+) in its aqueous solution, and base is a substance containing hydroxide which produces hydroxide ion (OH^-) in its aqueous solution."** It can be said on the basis of Arrhenius acid-base theory that acid ionises in water and produces H^+ and base ionises in water and produces OH^- ion. Thus, the theory of ionisation is involved in the basis of this theory.

$$HA\ (aq) \xrightarrow{H_2O} H^+(aq) + A^-(aq) \quad A^- = \text{Negative ion (e.g. } Cl^-, Br^-\ NO_3^-)$$

Acid **Hydrogen ion**

$$HNO_3\ (l) \xrightarrow{H_2O} H^+(aq) + NO_3^-(aq)$$

Nitric acid Nitrate ion,

$$HCl\ (l) \xrightarrow{H_2O} H^+(aq) + Cl^-(aq)$$

Hydorchloric acid Chloride ion

$$MOH\ (s) \xrightarrow{H_2O} M^+(aq) + OH^-(aq) \quad M^+ = \text{metal ion or } NH_4^+$$

Base **Hydroxide ion**

$$NaOH\ (s) \xrightarrow{H_2O} Na^+(aq) + OH^-(aq)$$

Sodium hydroxide Hydroxide ion

$$KOH\ (s) \xrightarrow{H_2O} K^+(aq) + OH^-(aq)$$

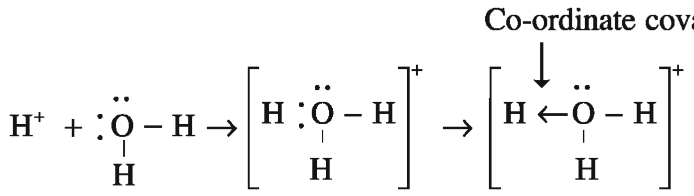
Potassium hydroxide Hydroxide ion

Arrhenius acid-base theory became very powerful yet, three limitations were observed. (1) It is applicable only to aqueous solutions. (2) Ammonia (NH_3) does not contain hydroxide ion even then its aqueous solution acts as base. It could not explain this. (3) According to this theory, H^+ is highly unstable, because it is hydrogen atom without electron i.e. positive hydrogen ion or proton. Its independent existence is not there, because it combines immediately with solvent viz $H^+ + H_2O \rightarrow H_3O^+$ Hydronium ion.

(2) Bronsted-Lowry Acid-Base Theory

To explain the limitations of Arrhenius acid-base theory, in 1923 Danish Chemist Johannes Bronsted and British Chemist Thomas Lowry presented a detailed concept of acid-base. It is known as Bronsted-Lowry acid-base theory. This theory can be applied to aqueous and non-aqueous solutions. In addition it can also give the explanation about the aqueous solution of a substance like ammonia to be base even though it does not contain hydroxide.

The substance which donates a proton ((H^+) to other subtance is called Bronsted-Lowry acid. The substance which accepts a proton from other substance is called Bronsted-Lowry base. In short, Bronsted-Lowry acid is a proton donating substance and Bronsted-Lowry base is a proton accepting substance. Thus, on the basis of this theory the concept of proton transfer is involved. According to this theory, the species responsible for acidity is not (H^+) but H_3O^+, because H^+ forms bond with water (H_2O) and forms hydrated hydrogen ion (H_3O^+). Generally, H_3O^+ is known as hydronium ion. In H_3O^+ there is a co-ordinate covalent bond between H^+ and H_2O, because the bond between them is formed by sharing of electron pair on oxygen atom of water.



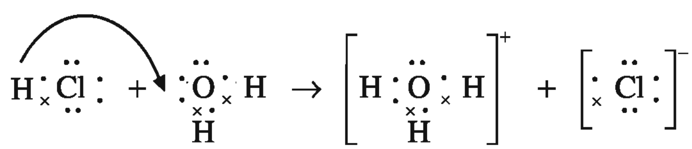
Hydronium ion

Now, we shall understand the Bronsted-Lowry acid-base concept by an example.

When hydorgen chloride gas is dissolved in water, hydrogen chloride gas donates proton to water; so hydrogen chloride gas is Bronsted-Lowry acid and as water accepts a proton, water is Bronsted-Lowry base.

$$HCl(g) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$$

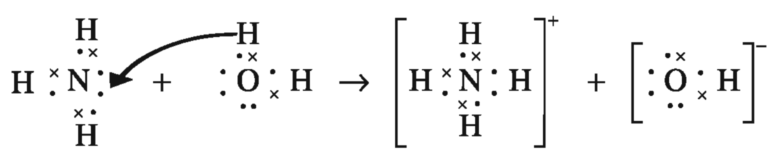
Acid Base



When ammonia gas (without hydroxide ion) is dissolved in water, ammonia gas water donates a proton to Bronsted-Lowry base, i.e. ammonia gas. Hence water is a Bronsted-Lowry acid.

$$NH_3(g) + H_2O(l) \rightarrow NH_4^+(aq) + OH^-(aq)$$

Base Acid



Here, in both the examples water acts as base and acid respectively. Thus, water acts both as acid or base according to the reaction; so it is called amphoteric. The amphoteric nature of water can be well understood by reaction between two molecules of water.

$$H_2O(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$$

Base Acid

7.3 Chemical Properties of Acids and Bases

Before the study of chemical reactions let us discuss acid-base, and how acid and base are formed. The reaction of oxide of non-metal with water, acid is formed, i.e.

oxide of non-metal + water $\rightarrow$ acid

e.g. $SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$

Sulphur trioxide Sulphuric acid

$CO_2(g) + H_2O(l) \rightarrow H_2CO_3(aq)$

Carbon dioxide → Carbonic acid

By reaction of oxides of metal with water, base is formed i.e.

Metal oxide + Water → Base

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

Sodium oxide → Sodium hydroxide

$CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(aq)$

Calcium oxide → Calcium hydroxide

$Li_2O(s) + H_2O(l) \rightarrow 2LiOH(aq)$

Lithium oxide → Lithium hydroxide

Chemical Properties of Acids

For the chemical reactions of acid, H^+ or H_3O^+ present in its aqueous solution; is responsible.

(1) Reaction of acid with metal: By reaction of acid with metal, salt corresponding to metal and dihydrogen gas are produced.

Acid + Metal → Salt of Metal + Dihydrogen gas

e.g.

$2HCl(aq) + Ca(s) \rightarrow CaCl_2(aq) + H_2(g)$

Hydrochloric acid → Calcium chloride

$H_2SO_4(aq) + Mg(s) \rightarrow MgSO_4(aq) + H_2(g)$

Sulphuric acid → Magnesium sulphate

Nitric acid being oxidising agent, by reaction with metal, water is produced instead of dihydorgen.

$8HNO_3(aq) + 3Zn(s) \rightarrow 3Zn(NO_3)_2(aq) + 2NO(g) + 4H_2O(l)$

Nitric acid → Zinc nitrate

Generally, noble metals like, Au, Ag, Pt do not react easily with acid.

(2) Reaction of acid with base : Salt and water are formed by reaction of acid with base. This reaction is called neutralisation reaction.

Acid + Base → Salt + Water

e.g. $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$

Sodium chloride

$H_2SO_4(aq) + 2KOH(aq) \rightarrow K_2SO_4(aq) + 2H_2O(l)$

Potassium sulphate

$2HNO_3(aq) + Ca(OH)_2(aq) \rightarrow Ca(NO_3)_2(aq) + 2H_2O(l)$

Calcium nitrate

$H_2CO_3(aq) + 2NaOH(aq) \rightarrow Na_2CO_3(aq) + 2H_2O(l)$

Sodium carbonate

$HCl(aq) + NH_4OH(aq) \rightarrow NH_4Cl(aq) + H_2O(l)$

Ammonium chloride

(3) **Reaction of acid with metal oxide :** This reaction is similar to the reaction of acid with base which means that by reaction of acid with metal oxide, salt and water are formed.

Acid + Metal oxide → Salt + Water

e.g. $2HCl(aq) + Na_2O(s) \rightarrow 2NaCl(aq) + H_2O(l)$

Sodium oxide

$H_2SO_4(aq) + MgO(s) \rightarrow MgSO_4(aq) + H_2O(l)$

Magnesium oxide Magnesium sulphate

$2HNO_3(aq) + CaO(s) \rightarrow Ca(NO_3)_2(aq) + H_2O(l)$

Calcium oxide Calcium nitrate

(4) **Reaction of acid with metal carbonate or metal hydrogen carbonate :** Most of the acids produce salt, water and carbon dioxide by reaction with metal carbonate or metal hydrogen carbonate.

Acid + Metal carbonate / Metal hydrogen carbonate → Salt + Water + Carbon dioxide gas

e.g. $2HCl(aq) + Na_2CO_3(aq) \rightarrow 2NaCl(aq) + H_2O(l) + CO_2(g)$

Sodium carbonate

$H_2SO_4(aq) + MgCO_3(s) \rightarrow MgSO_4(aq) + H_2O(l) + CO_2(g)$

Magnesium carbonate

$2HNO_3(aq) + K_2CO_3(aq) \rightarrow 2KNO_3(aq) + H_2O(l) + CO_2(g)$

Potassium carbonate

$HCl(aq) + NaHCO_3(aq) \rightarrow NaCl(aq) + H_2O(l) + CO_2(g)$

Sodium hydrogen carbonate

$H_2SO_4(aq) + 2NaHCO_3(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l) + 2CO_2(g)$

$HNO_3(aq) + NaHCO_3(aq) \rightarrow NaNO_3(aq) + H_2O(l) + CO_2(g)$

Sodium nitrate

Chemical Properties of Bases :

For the chemical reaction of base, the OH^- present in its aqueous solution is responsible.

(1) **Reaction of base with acid:** Reaction of base with acid forms salt and water. This reaction is called neutralisation.

Base + Acid → Salt + Water

e.g., $NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$

$2KOH(aq) + H_2SO_4(aq) \rightarrow K_2SO_4(aq) + 2H_2O(l)$

$Ca(OH)_2(aq) + 2HNO_3(aq) \rightarrow Ca(NO_3)_2(aq) + 2H_2O(l)$

$2NaOH(aq) + H_2CO_3(aq) \rightarrow Na_2CO_3(aq) + 2H_2O(l)$

$NH_4OH(aq) + HCl(aq) \rightarrow NH_4Cl(aq) + H_2O(l)$

(2) **Reaction of base with non-metal oxide:** This reaction is similar to the reaction of base with acid, that is, salt and water are formed by reaction of base with non-metal oxide.

Base + Non-metal oxide → Salt + Water

e.g., $Ca(OH)_2(aq) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(l)$

Calcium carbonate

$2NaOH(aq) + SO_3(g) \rightarrow Na_2SO_4(aq) + H_2O(l)$

Sodium sulphate

(3) **Reaction of base with some metals :** By reaction of strong base (see point 7.2) like sodium hydroxide with certain amphoteric metals (Zn, Al), salt and hydrogen gas are produced.

Base + Metal → Salt + Dihydrogen

e.g., $2NaOH(aq) + Zn(s) \rightarrow Na_2ZnO_2(aq) + H_2(g)$

Sodium zincate

$2KOH(aq) + 2Al(s) + 6H_2O(l) \rightarrow 2KAl(OH)_4(aq) + 3H_2(g)$

Potassium aluminate

Sodium zincate and Potassium aluminate are complex salts.

7.4 Solution and Its Concentration

We know that when common salt is dissolved in water, what is obtained is called solution of common salt. Here, common salt is a solute because its proportion in solution is less and water is a solvent because its proportion is more. Thus, **the system resulting when solute is dissolved in solvent is called solution.**

If we take same amount of water in three cups and add one, two and three table spoon common salt to first, second and third cups respectively, there will be difference in salty nature of solution in the three cups. The reason for this is that the amount of solute (common salt) in the same amount of solvent (water) is different. Similarly we can take one tea spoon common salt in the three cups and add one, two and three cups of water to first, second and third cups having common salt; even the difference is observed in the salty nature of the salt solution. The reason for this is that same amount of solute is dissolved in different volumes of solvent. Thus, the salty nature of solution depends on the relative amounts of solvent and solute. In scientific language, the amount of solute, in relation to amount of solvent is called concentration. Out of the two solutions, one having more salty nature has more concentration of common salt.

The solutions having definite concentrations are required in experiments of chemistry. The concentrations of solutions are expressed in different ways, viz percentage proportion, normality, molarity, molality, formality, ppm (parts per million). Units out of these normality and molarity are used more. Here, we will discuss only molarity. We will study the other units, in Standard 11 and 12. The molarity of solution means molelitre^{-1} concentration. **If 1 mole solute is dissolved in 1 litre solution, then the concentration of solutioin has 1 molarity.** In practice, 1 molarity is called 1 molar which is expressed in short as 1 M. If 2 moles of common salt are dissolved in 1 litre solution of common salt, it is said that concentration of the solution is 2 M. Similarly, if 1 mole glucose is dissolved in 500 ml solution, the concentration of solution is considered as 2 M. Because in 1 litre solution, 2 mole glucose dissolves as obtained by calculations. Now, if we wish to prepare 3 M NaCl aqueous solution, then 3 moles of NaCl should be dissolved in 1 litre solution i.e. 3 moles of NaCl should be dissolved in water and its total volume should be made 1 litre and not to add weight equal to 3 moles of NaCl in 1 litre water solvent. But the question arises, how to take 3 moles of NaCl ? On thinking, it will be found that it can be taken by weight. Hence, if NaCl is to be taken in mole, the relation between mole and mass should be thought of.

We have studied in Standard 9, about molecular mass (molecular weight) having relation between mole and mass. The unit of molecular mass is gram mole^{-1}. The molecular mass of NaCl is 58.5 gram mole^{-1}, i.e The amount 58.5 gram NaCl is called one mole amount of NaCl. Thus, **one mole of any amount equals to gram molecular mass should be taken.** Here, we should be more clear that **if the substance is in elemental form, then its atomic mass will have to be considered for 1 mole amount.** If the substane is in ion form even then its atomic mass is taken because there is no change in mass because of number of electric charge. Thus, the effect of gain or loss of electrons is not considered on its mass. Hence : 1 mole Na=1 mole Na^+ = 23 gram and 1 mole Cl = 1 mole Cl^- = 35.5 gram Cl. Thus, to prepare 3 M aqueous solution of NaCl, 3 moles of NaCl equal to 3 × 58.5 = 175.5 gram NaCl will have to be taken. 3 M NaCl solution can be prepared by dissolving 175.5 gram NaCl in some water and it gets dissolved, additional water should be added to make total volume equal to 1 litre. If this solution is to be prepared in 250 ml then, $\frac{175.5}{4} = 43.88$ gram NaCl quantity should be dissolved and the final volume will be 250 ml.

Example : 1

How will you prepare 100 ml aqueous solution of 2 M NaOH ?

Solutiion :

Molecular mass of NaOH = (Atomic mass of Na) + (Atomic mass of O) + (Atomic mass of H)

= (23) + (16) + (1)

= 40 gram mole^{-1}

According to the definition of molarity to prepare 1000 ml. 1 M NaOH solution, 40 gram NaOH will be required.

1000 ml. 1 M NaOH solution, 40 gram NaOH will be required.

$\therefore$ To prepare 100 ml. 2 M NaOH solution, $\frac{100 \times 2 \times 40}{1000 \times 1}$ gram NaOH will be required.

= 8 gram NaOH

Thus, 8 gram NaOH should be dissolved in water and the total volume of solution will be made 100 ml so that 2 M aqueous solution of NaOH can be prepared.

Example : 2

How will you prepare 250 ml 0.5 M aqueous solution of HCl ?

Solution :

Molecular mass of HCl = (Atomic mass of H) + (Atomic mass of Cl)

= (1) + (35.5)

= 36.5 gram mole^{-1}

According to definition of molarity,

To prapare 1000 ml 1 M HCl 36.5 gram HCl will be required

$\therefore$ To prepare 250 ml. 0.5 M HCl solution $\frac{250 \times 0.5 \times 36.5}{1000 \times 1}$ gram HCl will be required.

= 4.56 gram HCl.

Thus, by dissolving 4.56 gram HCl in water and making the total volume 250 ml, 250 ml 0.5 M aqueous solution of HCl can be prepared. We shall do the activity of filling in the blanks shown in Table 7.1 in order to prepare solutions of definite concentration.

Table 7.1 Aqueous solution of definite molarity of some substances.

Substance	Molecular mass (gram $mole^{-1}$)	Concentration of solution (M)	Volume of solution (ml)	Mass of substance (gram)
HCl	36.5	1	1000	36.5
NaOH	40	2	250	——
KOH	56	——	500	28
H_2SO_4	98	0.5	500	——
HNO_3	63	1	2000	——
$NaHCO_3$	84	1	——	21
Na_2CO_3	106	——	1000	53
$CuSO_4 .5H_2O$	249.5	0.1	1000	——
$FeSO_4. 7H_2O$	278	1	——	139

7.5 pH of Solution, pH Scale and Measurement of pH

Hydrogen ion concentration $[H^+]$ plays an important role in chemical and biochemical reactions. Some important reactions can be controlled by less concentration of hydrogen ion. The concentration of hydrogen or hydronium ion H_3O^+ in aqueous solution will have to be mentioned in molarity i.e. 2.8×10^{-4} M or 3.5×10^{-5} M or 4.9×10^{-9}M. The concentrations of hydronium ion in different substances can be as less as 10^{-7} M and as high as 1 M. If a graph is to be plotted of concentrations with such a high difference will be difficult. Thus, to remove the difficulties in expressing concentrations of hydronium ion in aqueous solution, biochemist of Denmark, S.P.L. Sorensen suggested a simple and convenient method to express concentration of hydronium ion in aqueous solution. It is known as pH scale.

Solution of pH and pH scale :

Generally pH expresses the concentration of hydronium ion in aqueous solutions. **Mathematically the negative logarithm to the base of 10 of molar concentration of H_3O^+ in aqueous solution is called pH.** If we write in the form of an equation, then,

$$pH = -\log_{10} [H_3O^+]$$

Distilled water is used as solvent in aqueous solution. H_3O^+ and OH^- ions are produced by self-ionisation of water

$$H_2O + H_2O \longrightarrow H_3O^+ + OH^-$$

Experimentally, it is proved that, $[H_3O^+] = [OH^-] = 10^{-7}$ M are present in distilled water at 298 K. We know that $[H_3O^+]$ of a solution is responsible for acidity and $[OH^-]$ of a solution is responsible for basicity. As concentrations of H_3O^+ and OH^- are same in distilled water, it acts as a neutral solvent. Hence, in aqueous solution of any substance if the concentration of H_3O^+ is more than 10^{-7} M the aqueous solution becomes acidic or if concentration of OH^- is more than 10^{-7} M, the aqueous solution becomes basic. The pH of acidic and basic solutions having different concentrations are shown respectively in Tables 7.2 and 7.3

Table 7.2 pH of aqueous acidic solutions

$[H_3O^+]$ in aqueous solution (In molarity)	$pH = -\log_{10}[H_3O^+]$	pH of aqueous solution
10^{-6}	$pH = -\log_{10}10^{-6} = 6 \log_{10}10 = 6$	6
10^{-5}	$pH = -\log_{10}10^{-5} = 5 \log_{10}10 = 5$	5
10^{-4}	$pH = -lo10g10^{-4} = 4 \log_{10}10 = 4$	4
10^{-3}	$pH = -\log_{10}10^{-3} = 3 \log_{10}10 = 3$	3
10^{-2}	$pH = -\log_{10}10^{-2} = 2 \log_{10}10 = 2$	2
10^{-1}	$pH = -\log_{10}10^{-1} = 1 \log_{10}10 = 1$	1
$10^{0} = 1$	$pH = -\log_{10}10^{0} = 0 \log_{10}10 = 0$	0

$[H_3O^+]$ increases ↓

pH decreases ↓

It can be said from the Table 7.2 that,

(i) In, aqueous acidic solution the value of $[H_3O^+]$ is more than 10^{-7} M and so the value of pH is less than 7 viz

For acidic solutions $[H_3O^+] > 10^{-7}$M and $pH < 7$

(ii) The acidity of a solution increases as concentration of H_3O^+ increases in aqueous acidic solution and so pH decreases. Opposite to this, as the concentration of H_3O^+ decreases, the acidity of the solution decreases and so pH increases. Thus, aqueous solution having pH 2 is more acidic than the solution having pH 4.

Like pH, the concentration of hydroxide ion OH^- in aqueous solution can also be expressed. **Mathematically, the negative logarithm to the base 10 of concentration of OH^- in aqueous solution is called pOH.** If we write as a formula, then

$$pOH = -\log_{10}[OH^-]$$

As we have discussed earlier, distilled water is neutral and in disstilled water at 298 K,

$$[H_3O^+] = [OH^-] = 1 \times 10^{-7}M$$

$\therefore \quad [H_3O^+] \times [OH^-] = 10^{-7} \times 10^{-7} = 10^{-14} M$

$\therefore \quad \log_{10}[H_3O^+] + \log_{10}[OH^-] = -14 \log_{10}10$

$\therefore \quad -\log_{10}[H_3O^+] - \log_{10}[OH^-] = 14 \log_{10}10$

$\therefore \quad \boxed{pH + pOH = 14}$

Table 7.3 pH of aqueous basic solutions

$[OH^-]$ in aqueous solution (in molarity)	$pOH = -\log_{10}[OH^-]$	pOH of aqueous solution	pH of aqueous solution
10^{-6}	$pOH = -\log_{10}10^{-6} = 6 \log_{10}10 = 6$	6	8
10^{-5}	$pOH = -\log_{10}10^{-5} = 5 \log_{10}10 = 5$	5	9
10^{-4}	$pOH = -\log_{10}10^{-4} = 4 \log_{10}10 = 4$	4	10
10^{-2}	$pOH = -\log_{10}10^{-3} = 3 \log_{10}10 = 3$	3	11
10^{-2}	$pOH = -\log_{10}10^{-2} = 2 \log_{10}10 = 2$	2	12
10^{-1}	$pOH = -\log_{10}10^{-1} = 1 \log_{10}10 = 1$	1	13
$10^{0} = 1$	$pOH = -\log_{10}10^{0} = 0 \log_{10}10 = 0$	0	14

$[OH^-]$ increases ↓

pH increases ↓

It can be said from Table 7.3 that

(i) In basic aqueous solutions, $[OH^-]$ is more than $10^{-7}M$ and so its pOH value is less than 7 and the value of pH is more than 7 viz.

For basic aqueous solution $[OH^-] > 10^{-7}M$, $pOH < 7$ and $pH > 7$

(ii) In aqueous basic solution, as the concentration of OH^- increases, basicity of the solution also increases, and pOH decreases but pH increases. Opposite to this as the concentration of OH^- decreases the basicity of the solution also decreases and pOH increases but pH decreases. Hence an aqueous solution having pH 12 is more basic than the aqueous solution having pH 9.

It is important here, to remember that in every acid, OH^- is present in addtion to H_3O^+ and in every base in addition to OH^-, $H_3^{+}O$ ions are present if one is more than the other will be less but the product of their concentrations, 10^{-14} remains constant.

In neutral solution concentrations of $[H_3O^+]$ and $[OH^-]$ are equal. As discussed earlier, in distilled water like neutral solution $[H_3O^+] = [OH^-] = 1 \times 10^{-7}$ M at 298 K. Hence, the pH of distilled water becomes 7. Thus, the pH of neutral aqueous solution is 7 viz.

For neutral aqueous solution $[H_3O^+] = [OH^-] = 10^{-7}M$ and $pH = 7$

Thus, from the overall discussion of pH scale, it can be said that pH scale is from 0 to 14. pH scale can be shown as in Fig 7.1

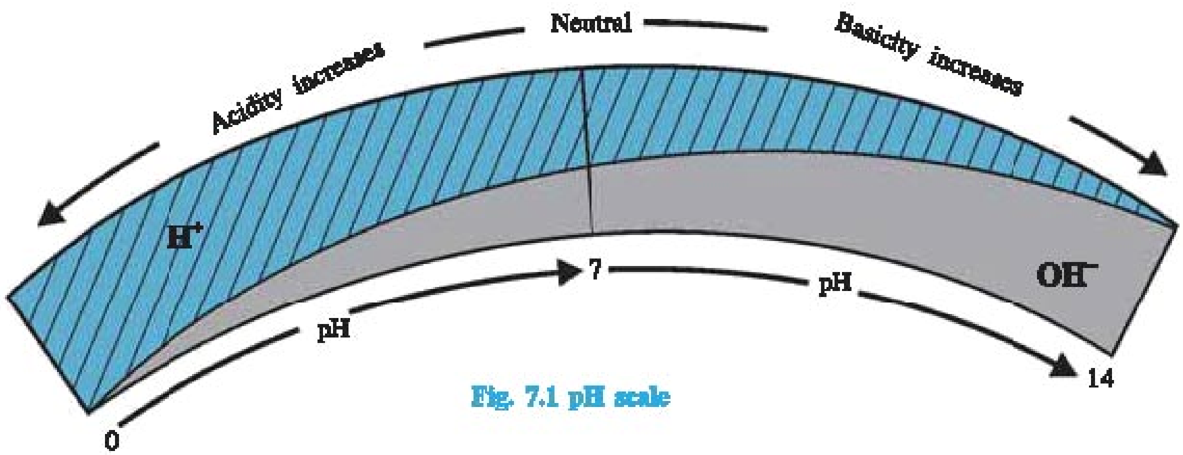


Fig. 7.1 pH scale

- **Limitations of pH scale :**

(1) pH scale is applilcable to aqueous solutions only.

(2) pH scale is applicable to aqueous solutions having concentration of hydornium ion less than 1 M. Hence, pH scale is from 0 to 14.

- **Measurement of pH :**

pH of aqueous solution can be measured by different methods. To measure approximate range of pH of aqueous solution, litmus paper; or approximate pH paper or universal indicator is used and for exact pH measurement the instrument called pH meter is used.

(1) To measure approximate pH range : Red and blue litmus papers are used to measure approximate pH range of aqueous solution. If a blue litmus paper is dipped into a solution, and if it turns red, then it can be said that the aqueous solution has acidic pH. In the same way, if a red litmus paper is dipped into a solution and if turns blue, then it can be said that the solution has basic pH. i.e. the value of pH can be considered between 7 and 14. If no effect is found on red or, blue litmus paper, that is, if red litmus paper remains red and blue litmus paper remains blue then it can be said that the solution is neutral. The pH of such solution is 7. Acidic or basic medium is important for certain reactions in industry. Litmus paper becomes useful in test for the nature of solution.

Fig 7.2 The value of pH according to change in colour of pH paper

(2) Approximate pH measurement : To measure approximate pH of aqueous solution, pH paper or universal indicator is used.

(i) **Use of pH paper :** Like litmus paper, if the pH paper is dipped into a solution whose pH value is to be known. Generally, the pH paper is of very light yellow colour. The pH of a solution can be determined by noting the change in the colour of pH paper. The information about what will be the pH of the solution when and what colour is obtained, is given with pH paper as shown in Fig 7.2.

If the pH paper is dipped in an aqueous solution and if turns pink, then the apprximate pH of the solution will be 2 . If the pH paper turns light green, then the approximate pH of the solution will be 7. Similarly, if pH paper turns blue then the approximate pH of solution will be 10.

(ii) **Use of Universal indicator :** One or two drops of universal indicator is added to a solution to know the value of pH. The pH of the solution is determined from the colour of the solution obtained during the process. Which colour is obtained is noted and what will be its pH is obtained by comparing with the colours shown on the bottle of the indicator. pH corresponding to the colour will be the pH of the solution. pH paper or universal indicator is mostly used for measurement of approximate pH of the solution during chemical reactions in industry and biochemical reactions.

Fig.7.3 Universal Indicator

(3) **To measure exact pH :** The instrument known as pH meter is used to determine the exact value of pH of aqueous solution. Two elecrodes of the pH meter are dipped in the solution whose exact pH is to be determined. The reading that is shown by the needle of pH meter indicates the exact pH of that solution. pH meter is standardised by a solution of known pH before it is used. Hence, exact pH of unknown solution can be measured. The pH-meter is an essential instrument for chemical industries. Now, we will do the activity of measuring pH of aqueous solutions of different substances.

Activity : 1

pH measurement of different aqueous solutions :

During this activity, ideally distilled water should be used to prepare aqueous solutions of different substances; but tap water can also be used for this activity because we do not have to carry out comparative study of the results.

- First of all take nine test tubes and number them from 1 to 9.
- In the test tube with numbers 1 to 4, take one tea spoon lemon juice, one tea spoon tomato juice, pinch of baking soda and pinch of washing soda respectively. Add water to all those four test tubes to half its level. Shake well each test tube and keep them as side.
- In the remaining 5 to 9 number test tubes take your urine, tap water, distilled water, dilute hydrochloric acid and dilute solution of sodium hydroxide to half its level.
- Arrange those nine test tubes in order in a test tube stand.
- Now, take test tube no.1 and distribute the solution in four equal volumes in three other empty test tubes. Thus, you will have No.1 test tube (lemon juice) solution in all the four test tubes.
- In all the four test tubes add successively red litmus paper, blue litmus paper, pH paper and two drops of universal indicator.
- Note in the observation table, the change in colour of litmus paper, and change in colour of pH paper and the change in colour of the solution to which universal indicator is added. Note also the approximate pH range and pH of solution on the basis of the change in colour.

- On the basis of the pH of the solution, determine its nature (acidic/basic/neutral) and also note them in the observation table.
- In the same way, measure the pH of solutions in test tubes No.2 to 9 and note your observations in the observation table.

Observation Table

Test tube. No.	Solution	Litmus paper			pH paper		Universal Indicator		Nature of Solution
		Change in colour of litmus paper		Approx-imate pH	Change in colour of pH Paper	Approx-imate pH	Change in colour of solution	Approx-imate pH	(Acidic or basic or neutral)
		Red Litmus paper	Blue Litmus paper						
1.	Lemon juice								
2.	Tomato Juice								
3.	Aqueous solution of baking soda								
4.	Aqueous solution of washing soda								
5.	Urine (self)								
6.	Tap water								
7.	Distilled water								
8.	Dilute hydrochloric acid (having concentration less than 1 M)								
9.	Dilute sodium hydroxide (having concentration less than 1 M)								

After finishing this activity, you will be competent to measure pH of aqueous solution of any substance, in this way.

7.6 Importance of pH in Everyday Life

(1) Importance of pH in existence of living beings : The physiological reactions occurring in human body take place in the range of 7.0 to 7.8 pH. Other living beings are not able to bear more change in pH. e.g When the water of acid rain mixes into water reservoirs like river or pond, then the pH of their water decreases. The existence of aquatic life kingdom like fish, micro-organisms and aquatic vegetation are being risked.

(2) Importance of pH in digestion of food : We know that stomach plays an importnat role in the digestion of food. As the food enters the stomach, hydrochloric acid is secreted in the stomach. The pH of this acid changes between 1 and 3. At this low value of pH the enzyme named pepsin becomes active. It becomes helpful in the digestion of protein in the food.

The proportion of protein is much more in food like fish, eggs, meat etc. Hydrochloric acid is secreted more for the digestion of such food. Because of this, sometimes, there is pain or irritation in the stomach. In common language, we call it 'acidity'. Basic substances are taken for the remedy of the acidity. They are known as antacids. Mostly, sodium hydrogen carbonate (Baking soda $NaHCO_3$) and magnesium hydroxide (Milk of magnesia $Mg(OH)_2$)) are used as antacids. Over and above, calcium carbonate ($CaCO_3$) and aluminium hydroxide ($Al(OH)_3$) are also known as antacid substances. Such liquid mixtures and cetrain tablets are available in market.

(3) Importance of pH in soil : The soil whose pH is between 6.5 to 7.3, the growth and development of shrubs is good. The soil having pH value less than 6.5 is called acidic soil. The farmers add lime (CaO) to the soil to neutralise this soil. The soil whose pH is more than 7.3 is called alkaline soil. The farmers add gypsum ($CaSO_4 . 2H_2O$) to neutralise this soil. Now, we will determine the type of the soil of our school, or house or garden or field by doing the activity of measuring pH of soil.

Activity : 2

- **To measure pH of soil and to determine its type.**
- Generally, to determine the pH of soil, the sample of soil is taken at the depth of nine inch in the soil, because the roots of most of the plant and the shrubs in the garden reach to the depth of nine inch. (The sample of soil can be collected from school, garden of the house or a field of the village).
- To prepare the solution of the sample of soil, take about 2 grams of soil sample in a test tube and add 5 ml. distilled water to it. Shake the test tube for a longer period so that soil and water mix properly (For preparation of solution of soil, the proportion of soil and water as 1:2.5 is considered ideal).
- Put the test tube in the stand without disturbance till the soil settles down in the test tube.
- After some time, filter the water layer that has separated in the test tube with the help of filter paper, collect the filtrate in other test tube. The filtrate must be a half to one ml. (Sometimes, the sample of soil is such that added 5 ml of water is being absorbed by the soil and the filtrate is not obtained). In such a case the activity should be repeated by adding 10 ml water instead of 5 ml water).
- Measure the pH of the obtained filtrate with the help of pH paper or universal indicator.
- Determine the type of the soil – acidic, basic or neutral on the basis of value of pH.

(4) Importance of pH in stopping decay of teeth : When the pH of the innerside of the mouth is less than 5.5, the decay of teeth takes place. The outer layer of teeth is made up of hard substance like calcium phosphate ($Ca_3(PO_4)_2$). It does not dissolve in water, but gets decayed when pH of inner side of mouth becomes less than 5.5. Acid is produced by decomposition of particles of food and sachharides by bacteria inside the mouth after taking meals. It decreases the pH inside the mouth. Hence decay of teeth takes place. To protect your teeth, good habit should be formed to clean the teeth after taking meals. The tooth powder and the tooth paste that are used for teeth cleaning possess basic nature. They neutralise the acid produced inside the mouth and protect teeth from decay.

(5) In the remedy of effect of bite of honeybee: We know that when red ant bites we feel irritation. The reason for this is the entry of formic acid in our body. Similarly, when the honey bee bites, we feel pain and irritation at the place of bite. Also, there is swelling around the place of bite: because the poison that is added in our body by the bite of honey-bee is acidic. In this poison, more acidic natured substance Melittin is present. Melittin is a polypeptide containing 26 amino acids. To get relief from the effect of bite of honey-bee, aqueous solutions of basic substance like baking soda is applied around the place of bite, which neutralises the acidic poison.

Table 7.4 The pH values, at 298 K, of some solutions associated with everyday life

No.	Solution	pH
1.	Pure water	7.0
2.	Sea water	8.5
3.	Stomach fluid	1.0 - 3.0
4.	Saliva	6.5 - 7.5
5.	Blood	7.4
6.	Urine	5.5 - 7.5
7.	Milk	6.3 - 6.6
8.	Lemon juice	2.2 - 2.4
9.	Tomato juice	4.0 - 4.4
10.	Coffee	4.5 - 5.5
11.	Aqueous solution of baking soda	8.5
12.	Aqueous solution of washing soda	12.0
13.	Milk of magnesia	10.5
14.	Vinegar (4%)	2.5

Example 3 :

Calculate pH of aqueous solution whose H_3O^+ concentration is 2.5×10^{-5}M. Which nature–acidic, basic or neutral – this solution will possess ?

Solution : In aqueous solution $[H_3O^+] = 2.5 \times 10^{-5}$ M

Now, $\quad pH = -log_{10}[H_3O^+]$

$= -log_{10}(2.5 \times 10^{-5})$

$= -log_{10}(2.5) - log_{10} 10^{-5} \quad (\because log(mn) = logm + logn)$

$= -log_{10}(2.5) + 5 \ log_{10}10$

Using logaritham table,

$= -0.3979 + 5 \ (\because \ log_{10}10 = 1)$

$\therefore \quad pH = 4.6021 \simeq 4.60$

Thus, the value of pH of an aqueous solution having concentration 2.5×10^{-5} M will be 4.60. The concentration of H_3O^+ is more than 10^{-7}M and pH is less than 7, so the solution will possess acidic nature.

Example 4 :

Calculate concentration of H_3O^+ in an aqueous solution whose pH value is 5.5.

Solution : $\quad pH = -log_{10} [H_3O^+]$

$\therefore \quad 5.5 = -log_{10} [H_3O^+]$

$\therefore \quad log_{10}[H_3O^+] = -5.5$

$\therefore \quad log_{10}[H_3O^+] = 6 - 5.5 - 6$

$\therefore \quad log_{10}[H_3O^+] = -6 + 0.5$

$\therefore \quad log_{10}[H_3O^+] = \bar{6}.5000$

$\therefore \quad [H_3O^+] = \text{antilog} (\bar{6}.5000)$

$= 0.3162 \times 10^{-5}$ M

$\therefore \quad [H_3O^+] = 3.162 \times 10^{-6}$ M

$\therefore \quad [H_3O^+] = 3.16 \times 10^{-6}$ M

Thus, the value of pH is less than 7 and concentration of H_3O^+ in aqueous solution is more than 10^{-7} M and so the solution will be acidic.

7.7 Comparison of Concentrations of Acid-Base on the Basis of pH

Earlier in point 7.5 we have understood that the aqueous solution having pH 2 is more acidic than, the aqueous solution having pH 4 and the aqueous solution having pH 12 is more basic than the aqueous solution having pH 9. But the question will arise that how many times acidic or basic those solutions will be ? Let us understand this matter with an example.

Example 5 :

How many times the aqueous solution having pH 2 will be more acidic than aqueous solution having pH 4 ?

Solution : For aqueous solution having pH 4,

$pH = -log_{10}[H_3O^+]$

$\therefore \quad -log_{10}[H_3O^+] = 4$

$\therefore \quad log_{10}[H_3O^+] = -4$

$\therefore \quad [H_3O^+] = 10^{-4}$ M $\qquad (\because log_a b = m \text{ for } a^m = b)$

Similarly $[H_3O^+]$ in aqueous solution having pH 2 = 10^{-2}M

$$\frac{[H_3O^+] \text{ in aqueous solution having pH 2}}{[H_3O^+] \text{ in aqueous solution having pH 4}} = \frac{10^{-2}M}{10^{-4}M} = 10^2 = 100$$

Thus, the concentration of aqueous solution having pH 2 is 100 times more concentrated than the aqueous solution having pH 4, i.e. it will be 100 times more acidic.

Thus, the comparison of acidity of the aqueous solutions A and B having different pH can be carried out according to Table 7.5.

Table 7.5 Comparison of acidity of two acidic aqueous solutions

pH of solution A	pH of Solution B	$[H_3O^+]$ in Solution A (in molarity)	$[H_3O^+]$ in Solution B (in molarity)	How much less is the pH of Solution A than pH of Solution B	How many times is the concentration of H_3O^+ in solution of A than the concentration in solution of B ?
5	6	10^{-5}	10^{-6}	1	10^1 = 10
3	5	10^{-3}	10^{-5}	2	10^2 = 100
2	5	10^{-2}	10^{-5}	3	10^3 = 1000
2	6	10^{-2}	10^{-6}	4	10^4 = 10000
1	6	10^{-1}	10^{-6}	5	10^5 = 100000
2	4.5	10^{-2}	$10^{-4.5}$	2.5	$10^{2.5}$ = antilog(2.5) = 316.2
1.9	5.3	$10^{-1.9}$	$10^{-5.3}$	3.4	$10^{3.4}$ = antilog (3.4) = 2152

Thus, it can be said from Table 7.5 that if the diffrence in pH of two acidic aqueous solutions is x, then solution having less pH will possess H_3O^+ concentration 10^x times or antilog x times more acidic.

Now, we shall study Table 7.6 to compare the basicity of two basic aqueous solutions A and B having different pH values.

Table 7.6 Comparison of basicity of two basic aqueous solutions

pH of Solution A	pH of Solution B	pOH of Solution A	pOH Solution B	$[OH^-]$ in Solution A (in molarity)	$[OH^-]$ in Solution B (in molarity)	How much more is the pH of Solution B than pH of Solution A	Concentration of OH^- in Solution B is how many times more than that of Solution A
12	13	2	1	10^{-2}	10^{-1}	1	$10^1 = 10$
11	13	3	1	10^{-3}	10^{-1}	2	$10^2 = 100$
9	12	5	2	10^{-5}	10^{-2}	3	$10^3 = 1000$
8	12	6	2	10^{-6}	10^{-2}	4	$10^4 = 10000$
8	13	6	1	10^{-6}	10^{-1}	5	$10^5 = 100000$
9.3	12.8	4.7	1.2	$10^{-4.7}$	$10^{-1.2}$	3.5	$10^{3.5}$ = antilog(3.5) = 3612
8.9	11.5	5.1	2.5	$10^{-5.1}$	$10^{-2.5}$	2.6	$10^{2.6}$ = antilog(2.6) = 398.1

Thus, it can be said from Table 7.6, that if x is the difference between pH of two basic aqueous solutions, then solution having more pH possesses, OH^- concentration 10^x or antilog x times more than the solution having less pH, i.e. that solution will be 10^x or antilog x times more basic.

(1) Strong and Weak Acids :

If we try to prepare the list of known acids, then we can conclude that acids like hydrochloric acid, sulphuric acid, nitric acid are used in laboratory and acids like acetic acid (in vinegar), lactic acid in curd, butter milk, citric acid (in lemon, orange), tartaric acid (in tamarind), oxalic acid (in tomato) are used in everyday life. Out of these acids, if mineral acids like hydrochloric acid, sulphuric acid and nitric acid, when dissolved in water, they get completely ionised. These acid subtances are known as strong acids. In the aqueous solution of strong acid, total solute substance is in the form of ions, i.e. the solute substance is ionised to H_3O^+

Example :

(1) In 1 M HCl aqueous solution, concentrations of H_3O^+ and Cl^- are 1 M

$$\underset{1\ M}{HCl(aq)} + H_2O(l) \rightarrow \underset{1\ M}{H_3O^+(aq)} + \underset{1\ M}{Cl^-(aq)}$$

(2) In 1 M H_2SO_4 aqueous solution, concentrations of H_3O^+ and SO_4^{2-} are 2 M and 1 M respectively, because two moles H_3O^+ are formed by ionisation of one mole H_2SO_4.

$$\underset{1\text{ M}}{H_2SO_4(aq)} + 2H_2O(l) \rightarrow \underset{2\text{ M}}{2H_3O^+(aq)} + \underset{1\text{ M}}{SO_4^{2-}(aq)}$$

When acetic acid, lactic acid, citric acid, tartaric acid, oxalic acid are dissolved in water, there is incomplete ionisation of them. These acid-substances are known as weak acids. In aqueous solutions of weak acid, very less amount of solute is ionised to H_3O^+, the remaining amout exists in undissociated form, i.e. concentration of H_3O^+ is not 1 M in 1 M CH_3COOH aqueous solution but it is very less (Approximately 2 to 3%). Immediately, a question will strike to our mind, that what will be H_3O^+ concentration in this solution. To get the answer of this questions we need first to know ionisation constant K_a of CH_3COOH and will have to do some calculations. We shall study these calculations in Standard 11. At present, we shall study that **the acid which ionises or dissociates completely in aqueous solution is called strong acid, and the acid which ionises or dissociates incompletely is called a weak acid.**

We use the words like concentrated and dilute in the laboratory. e.g. concentrated hydrochloric acid, dilute hydrochloric acid, concentrated sulphuric acid, dilue sulphuric acid, concentrated nitric acid, dilute nitric acid etc. In concentrated solution the amount of solute substance is in larger propotion while in dilute solutions it is much less. Hydrochloric acid having concentration 35-38%, sulphuric acid having concentration 98%, nitric acid having concentration 70-72% and acetic acid having concentration 100% are concentrated acids. To prepare dilute solutions of these acids, three parts of water is taken to which one part of acid is added. Both strong and weak acids can be concentrated acid and dilute acid. We find this acid in laboratory in both the concentrated and dilute forms. Similarly acetic acid is a weak acid and it is available in laboratory, in both the concentrated and dilute forms. We should clearly understand that concentrated and dilute have no relation with strong and weak. Storng and weak types are called on the basis of their ionisation while concentrated and dilute show their magnitude or the amount of solute dissolved.

(2) Strong and Weak Bases :

Strong and Weak Bases : Sodium hydroxide, potassium hydroxide when dissolved in water, they are completely ionised. These basic substances are known as strong bases. In aqeuous basic solution, total solute substance is in the form OH^- ions because of its complete ionisation, i.e. the total solute substance is ionised in the form of OH^- .

Example :

1 M NaOH aqueous solution, the concentrations of Na^+ and OH^- are 1 M .

$$\underset{1\text{ M}}{NaOH(aq)} \rightarrow \underset{1\text{ M}}{Na^+(aq)} + \underset{1\text{ M}}{OH^-(aq)}$$

The known bases like ammonium hydroxide (NH_4OH) when dissolved in water, they are incompletely ionised. These substances are called weak bases. Aqueous solution of calcium hydroxide is weak base. In the aqueous solution of weak base, very less amount (2 to 3%) of solute is ionised to OH^- i.e. In aqueous solution of 1M NH_4OH, the concentration of OH^- is not 1 M but it is very less. We shall study the calculation of OH^- concentration in weak base in Standard 11. At present we shall study only this much that **the base which ionises or dissociates completely is called strong base and the base which ionises or dissociates partially or incompletely is called weak base.**

Example 6 :

Calculate pH of aqueous solution of 0.05 M HCl

Solution : HCl being a stong acid ionises completely in water.

$$HCl(aq) + H_2O(l) \xrightarrow[\text{ionisation}]{\text{complete}} H_3O^+(aq) + Cl^-(aq))$$

0.05 M   0.05 M

Here, $[H_3O^+] = 0.05$ M

$$\begin{aligned} \text{Now, pH} &= -\log_{10}[H_3O^+] \\ &= -\log_{10}(0.05) \\ &= -\log_{10}(5 \times 10^{-2}) \\ &= -\log_{10}5 + 2\log_{10}10 \\ &= -0.6990 + 2 \\ &= 1.\ 3010 \\ &\approx 1.30 \end{aligned}$$

Thus, pH of aqueous solution of 0.05 M HCl will be 1.30.

Example 7 :

Calculate pH of aqueous solution of 0.007 M NaOH

Solution : As NaOH is a strong base, it is completely ionised.

$$NaOH(aq) + H_2O\ (l) \xrightarrow[\text{ionisation}]{\text{complete}} Na^+(aq) + OH^-(aq)$$

0.007M   0.007M

Here, $[OH^-] = 0.007$ M

$$\begin{aligned} \text{Now, pOH} &= -\log_{10}[OH^-] \\ &= -\log_{10}(0.007) \\ &= -\log_{10}(7 \times 10^{-3}) \\ &= -\log_{10}7 + 3\log_{10}10 \\ &= -0.8451 + 3 \end{aligned}$$

$\therefore$ pOH $= 2.1549$

But NaOH being base, its pH can be calculated as follows :

We know that pH + pOH = 14

$\therefore$ pH = 14 – 2.1549

$\therefore$ pH = 11.8451 $\approx$ 11.85

Thus, pH of 0.007 M aqueous solution of NaOH will be 11.85

Example 8 :

3 litre aqueous solution is prepared by dissolving 4.9 gram H_2SO_4 in water, calculate pH of this solution.

Solution : To calculate pH of an aqueous solution, we should know concentration of H_3O^+ in the solution, in molelitre^{-1}.

Molecular mass of H_2SO_4 is 98 gram mole^{-1}

$$\text{Moles of } H_2SO_4 = \frac{\text{Weight of } H_2SO_4}{\text{Molecular mass of } H_2SO_4}$$

$$= \frac{4.9 \text{ gram}}{98 \text{ gram mole}^{-1}}$$

$$= 0.05 \text{ mole}$$

$$\text{Concentration of } H_2SO_4 \text{ (mole litre}^{-1}) = \frac{\text{Moles of } H_2SO_4}{\text{Volume of solution (Litre)}}$$

$$= \frac{0.05 \text{ mole}}{3 \text{ litre}}$$

$$= 0.0167 \text{ mole litre}^{-1}$$

H_2SO_4 is a storng acid and it is completely ionised in water.

$$H_2SO_4(aq) + 2H_2O(l) \xrightarrow[\text{ionisation}]{\text{complete}} 2H_3O^+ (aq) + SO_4^{2-}(aq)$$

0.0167 M 2×0.0167 M

= 0.0334 M

Here, $[H_3O^+]$ = 0.0334 M

$$\begin{aligned}
\text{Now, pH} &= -\log_{10}[H_3O^+] \\
&= -\log_{10}(0.0334) \\
&= -\log_{10}(3.34 \times 10^{-2}) \\
&= -\log_{10}(3.34) + 2\log_{10}10 \\
&= -0.5237 + 2 \\
&= 1.4763 \\
&\approx 1.48
\end{aligned}$$

$\therefore$ pH = 1.48

Thus, pH of H_2SO_4 solution will be 1.48

Example 9 :

An aqueous solution of nitric acid has pH 2.32 at 298 K temperature. The volume of this solution is made eight times than its original volume. What will be the pH of this dilute solution obtained ?

Solution : Here, pH of aqueous solution of nitric acid is 2.32.

$$pH = 2.32$$

$\therefore \quad -\log_{10}[H_3O^+] = 2.32$

$\therefore \quad \log_{10}[H_3O^+] = -2.32$

$\therefore \quad \log_{10}[H_3O^+] = 3 - 2.32 - 3$

$\therefore \quad \log_{10}[H_3O^+] = 0.68 - 3$

$\therefore \quad \log_{10}[H_3O^+] = \bar{3}.68$

$\therefore \quad [H_3O^+] = \text{antilog}\ (\bar{3}.68)$

$= 0.4786 \times 10^{-2}$ M

When water is added to aqueous solution of nitric acid and the original volume of the solution is increased by 8 times, the concentration of solution will be decreased by 8 times.

$\therefore$ $[H_3O^+]$ in diluted aqueous solution of nitric acid $= \dfrac{0.4786 \times 10^{-2}\ M}{8}$

$= 0.0598 \times 10^{-2}M$

$= 5.98 \times 10^{-4}M$

Now, $\quad pH = -\log_{10}[H_3O^+]$

$= -\log_{10}(5.98 \times 10^{-4})$

$= -\log_{10}(5.\ 98) + 4 \log_{10}10$

$= -\ 0.7767 + 4$

$= 3.2233$

≈ 3.22

$\therefore$ pH = 3.22

Thus, pH of diluted nitric acid will be 3.22.

7.8 Neutralisation

Salt and water are formed by reaction of acid with base or base with acid. This reaction is known as neutralisation. With the help of the experiment based on this reaction, the concentration of unknown acid or base can be known. This experiment is called neutralisation titration.

Its general study has been done by you in earlier standards, and detailed understanding through experiments will be studied in next standards. Now, we study neutralisation reactions between some acids and bases.

(1)	$HCl(aq)$	+	$NaOH(aq)$	$\rightarrow$	$NaCl(aq)$	+	$H_2O(l)$
	Strong acid		Strong base		Salt		Water
(2)	$HNO_3(aq)$	+	$KOH(aq)$	$\rightarrow$	$KNO_3(aq)$	+	$H_2O(l)$
	Strong acid		Strong base		Salt		Water
(3)	$H_2CO_3(aq)$	+	$2NaOH(aq)$	$\rightarrow$	$Na_2CO_3(aq)$	+	$2H_2O(l)$
	Weak acid		Stong base		Salt		Water
(4)	$CH_3COOH(aq)$	+	$NaOH(aq)$	$\rightarrow$	$CH_3COONa(aq)$	+	$H_2O(l)$
	Weak acid		Stong base		Salt		Water
(5)	$HCl(aq)$	+	$NH_4OH(aq)$	$\rightarrow$	$NH_4Cl(aq)$	+	$H_2O(l)$
	Strong acid		Weak base		Salt		Water
(6)	$HNO_3(aq)$	+	$NH_4OH(aq)$	$\rightarrow$	$NH_4NO_3(aq)$	+	$H_2O(l)$
	Strong acid`		Weak base		Salt		Water
(7)	$CH_3COOH(aq)$	+	$NH_4OH(aq)$	$\rightarrow$	$CH_3COONH_4(aq)$	+	$H_2O(l)$
	Weak acid		Weak base		Salt		Water
(8)	$H_2CO_3(aq)$	+	$2NH_4OH(aq)$	$\rightarrow$	$(NH_4)_2CO_3(aq)$	+	$2H_2O(l)$
	Weak acid		Weak base		Salt		Water

Will the pH of all the salts produced by all these reactions will be neutral or pH will be 7 ? No. The pH of aqueous solutions of salts Na_2CO_3 and CH_3COONa produced by reactions (3) and (4) is more than 7, because the salt hydrolyses in water and produces OH^-.

(9) $$Na_2CO_3(aq) \xrightarrow{\text{Ionisation}} 2Na^+(aq) + CO_3^{2-}(aq)$$

$$CO_3^{2-}(aq) + H_2O(l) \xrightarrow{\text{Hydrolysis}} HCO_3^-(aq) + OH^-(aq)$$

(10) $$CH_3COONa\ (aq) \xrightarrow{\text{Ionisation}} CH_3COO^-(aq) + Na^+(aq)$$

$$CH_3COO^-(aq) + H_2O(l) \xrightarrow{\text{Hydrolysis}} CH_3COOH(aq) + OH^-(aq)$$

Thus, the aqueous solutions or the salts produced by neutralisation of weak acid with strong base possesses basic nature. The pH of aqueous solution of salts NH_4Cl and NH_4NO_3 produced by reactions (5) and (6) have pH less than 7, because the salt hydrolyses in water and produces H_3O^+.

(11) $NH_4Cl(aq) \xrightarrow{\text{Ionisation}} NH_4^+(aq) + Cl^-(aq)$

$NH_4^+(aq) + H_2O(l) \xrightarrow{\text{Hydrolysis}} NH_3(aq) + H_3O^+(aq)$

(12) $NH_4NO_3(aq) \xrightarrow{\text{Ionisation}} NH_4^+(aq) + NO_3^-(aq)$

$NH_4^+(aq) + H_2O(l) \xrightarrow{\text{Hydrolysis}} NH_3(aq) + H_3O^+(aq)$

Thus, **the aqueous solutions of salts produced by neutralisation of weak base and strong acid possess acidic nature.** The pH of aqueous solution of salts NaCl and KNO_3 produced by reaction (1) and (2) have pH 7, because they do not hydrolyse like the salts produced by reactions (3) to (6). Thus, **the aqueous solutions of salts produced by strong acid and strong base possess neutral nature.**

The pH of the aqueous solutions of the salts CH_3COONH_4 and $(NH_4)_2CO_3$ produced by reactions (7) and (8) have pH 7 and slightly more than 7 respectively. The pH of the aqueous solutions of this type of salts have sometimes pH less than 7. If **acid and base are equally weak then the aqueous solution of the salt produced is neutral, otherwise, it may be acidic or basic according to difference in their weakness.**

The discussion about nature of aqueous solutions of salts produced during neutralisation is given in Table 7.7

Table 7.7 Nature of aqueous solution produced during neutralisation

Acid	Base	Example of salt produced	Nature of aqueous solution of salt
Strong	Strong	NaCl, KNO_3	Neutral
Strong	Weak	NH_4Cl, NH_4NO_3	Acidic
Weak	Strong	Na_2CO_3, CH_3COONa	Basic
Weak	Weak	CH_3COONH_4, $(NH_4)_2CO_3$	Neutral or slightly acidic or slightly basic

If you desire, you can test the nature of the salts mentioned in Table 7.7 by preparing the aqueous solution of the salt in distilled water and test with the help of litmus paper, pH paper or universal indicator.

7.9 Salt

Salt is available in large proportion in nature. The minerals and rocks in the form of the cover of the earth are directly or indirectly salts. Common salt (NaCl), baking soda ($NaHCO_3$) and washing soda ($Na_2CO_3.1OH_2O$) used in everyday life are salts. The substances like sodium chloride (NaCl), sodium sulphate (Na_2SO_4), ammonium chloride (NH_4Cl), calcium chloride ($CaCl_2$), calcium sulphate ($CaSO_4$), barium sulphate ($BaSO_4$), potassium sulphate (K_2SO_4), silver nitrate ($AgNO_3$), silver chloride (AgCl), barium chloride ($BaCl_2$) etc. are also the examples of the salt. Salt can be prepared in the laboratory by reaction of acid with base or base with acid. Like acid and base, salts also exhibit chemical properties.

Chemical Properties of Salts

(1) **Reaction of salt with acid :** Salt reacts with certain acids and forms other salt and acid.

Salt + Acid → Other salt + Acid

e.g. $BaCl_2(aq) + H_2SO_4(aq) \rightarrow BaSO_4(s) + 2HCl(aq)$

$AgNO_3(aq) + HCl(aq) \rightarrow AgCl(s) + HNO_3(aq)$

(2) **Reaction of salt with base :** Salt reacts with certain bases and form other salt and base.

Salt + Base → Other salt + Base

e.g. $Na_2SO_4(aq) + Ba(OH)_2(aq) \rightarrow BaSO_4(s) + 2NaOH(aq)$

$K_2SO_4(aq) + Ca(OH)_2(aq) \rightarrow CaSO_4(s) + 2KOH(aq)$

(3) **Reaction of salt with other salt :**

Salt + Other Salt → New Salt + New salt

e.g.

$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$

$CaCl_2(aq) + Na_2SO_4(aq) \rightarrow CaSO_4(s) + 2NaCl(aq)$

You can test the properties of all the three salts in the laboratory.

What have you learnt ?

- About three hundred years ago Robert Boyle defined acid-base on the basis of chemical properties. This type of definition is known as operational or old definition.
- **Modern concepts about acid-base.**

(1) **Arrhenius Acid-Base theory :** "Acid is a compound containing hydrogen which produces hydrogen ion (H^+) in its aqueous solution and base is a compound containing hydroxide which produces hydroxide ion in its aqueous solution." In the basis of this theory the concept of ionisation is involved.

(2) **Bronsted-Lowry Acid-Base theory :** "The substance which can donate a proton (H^+) to other substance is called Bronsted-Lowry Acid. The substance which accepts a proton (H^+) from other substance is called Bronsted-Lowry base." Thus, on the basis of this theory, the concept of proton transfer is involved.

- **From which and how acid and base are prepared ?**

(1) Non-metal oxide + Water → Acid

(2) Metal oxide + Water → Base

- **Chemical properties of Acid :**

(1) Acid + Metal → Salt + Dihyrogen gas

(2) Acid + Base → Salt + Water

(3) Acid + Metal oxide → Salt + Water

(4) Acid + Metal carbonate / Metal hydrogen carbonate → Salt + Water + Carbon dioxide gas

- **Chemical properties of base :**

(1)	Base + Acid	$\rightarrow$	Salt + Water
(2)	Base + Nonmetal oxide	$\rightarrow$	Salt + Water
(3)	Base + Metal	$\rightarrow$	Salt + Diyhdrogen gas

The concentration of aqueous solutions of acid, base and salt are generally expressed in molarity. Molarity means concentration in molelitre^{-1}. If 1 mole solute is dissolved in 1 litre solution then it can be said that the molarity of the solution is 1. In other words, if we say, if an amount equal to one gram molecular mass of a solute is dissolved in 1 litre solution then the concentration of solution (molarity) can be said to be 1 (1 molar or 1 M)

In 1929, Biochemist of Denmark, S.P.L Sorensen suggested a simple and convenient method to express concentration of hydronium ion in aqueous solution, which is known as pH scale.

- $pH = -\log_{10}[H_3O^+]$
- $pOH = -\log_{10}[OH^-]$
- $pH + pOH = 14$
- For acidic aqueous solution $[H_3O^+] > 10^{-7}$ M and $pH < 7$ and as $[H_3O^+]$ inceraes pH decreases.
- For basic aqueous solution $[OH^-] > 10^{-7}$ M, $pOH < 7$ and $pH > 7$ and as $[OH^-]$ increases pOH decreases but pH increases.
- For neutral solution $[H_3O^+] = [OH^-] = 10^{-7}$ M and $pH = 7$
- pH scale ranges from 0 to 14.
- pH scale is applicable to aqueous solutions.
- pH scale is applicable to aqueous solutions having hydronium ion concentration less than 1 M.
- To measure approximate pH range of an aqueous solution, litmus paper, for approximate pH, pH paper or universal indicator and for exact pH measurement, pH meter instrument is used.
- If the difference between pH of two aqueous acidic solutions is x, then the solution having less pH possesses H_3O^+ concentration 10^x or antilog x times more than the aqueous solution having more pH, i.e. that solution is 10^x or antilog x times more acidic.
- If the difference between pH of two aqueous basic solutitons is x, then the pH of the aqueous solution having more pH has concentration 10^x or antilog x times more than the concentration of OH^- of the aqueous solution having less pH i.e. the solution is 10^x or antilog x times more basic.
- The substances like acid or base which ionise completely in water when dissolved are called strong acid or strong base and if ionisation is incomplete, they are called weak acid or weak base.
- **Strong acids :** HCl, HNO_3, H_2SO_4

- **Weak acids :** Acetic acid, lactic acid, citric acid, tartaric acid, oxalic acid.
- **Strong base :** NaOH, KOH
- **Weak base :** NH_4OH, $Ca(OH)_2$

Reaction of acid with base or base with acid results in the formation of salt and water. This reaction is called neutralisation reaction.

Type of acid	Type of Base	Example of Salt formed	pH of aqueous solution of salt and its nature
Strong	Strong	NaCl, KNO_3	pH = 7 (Neutral)
Stong	Weak	NH_4Cl, NH_4NO_3	pH < 7 (Acidic)
Weak	Strong	Na_2CO_3, CH_3COONa	pH > 7 (Basic)
Weak	Weak	CH_3COONH_4, $(NH_4)_2CO_3$	pH = 7 or slightly more or less than 7 (Neutral or Slightly acidic or slightly basic)

- **Chemical properties of salts :**

(1) Salt + Acid → Other salt + Other acid

(2) Salt + Base → Other salt + Other base

(3) Salt + Other salt → New salt + New salt

EXERCISE

1. Select the proper choice from the given multipule choices :

(1) What is formed by reaction of non-metal oxide with water ?

(A) Acid (B) Base (C) Salt (D) Metal

(2) Acid + Metal-oxide → ?

(A) Base + Water (B) Salt + Water (C) Base + Salt (D) Metal + Salt

(3) Which gas is produced by reaction of base with metal ?

(A) Carbon dioxide (B) Dioxygen (C) Dihydrogen (D) Dinitrogen

(4) 500 ml aqueous solution is prepared by dissolving 2 moles of HCl in water. What will be the molarity of this solution ?

(A) 1 (B) 2 (C) 3 (D) 4

(5) What is correct for acidic aqueous solution ?

(A) $[H_3O^+] = 10^{-7}$ M (B) $[H_3O^+] < 10^{-7}$M

(C) $[H_3O^+] > 10^{-7}$ M (D) $[H_3O^+] < [OH^-]$

(6) Which of the following solutions is the most basic ?

(A) pH = 8.2 (B) pH = 9.3 (C) pH = 11.5 (D) pH = 10.6

(7) Which statement is incorrect ?

(A) pH scale was presented by S.P.L Sorensen.

(B) pH scale ranges between 0 to 14.

(C) pH scale is applicable to only non-aqueous solutions.

(D) pH scale is applicable to only aqueous solutions.

(8) How is the exact pH of an aqueous solution measured ?

(A) pH paper (B) Litmus paper

(C) pH meter (D) Universal indicator

(9) Which of the following substances is an antacid ?

(A) NaCl (B) $Mg(OH)_2$ (C) HCl (D) H_2SO_4

(10) The aqueous solution having pH 11 is how many times less basic than aqueous solution having pH 8 ?

(A) 3 (B) 30 (C) 300 (D) 1000

(11) Which of the following is strong acid ?

(A) Acetic acid (B) Citric acid (C) Nitric acid (D Oxalic acid

(12) What type of substance is NH_3 ?

(A) Strong acid (B) Weak acid (C) Strong base (D) Weak base

(13) pH + pOH = ?

(A) 7 (B) 0 (C) 14 (D) 10

(14) Which formula is correct ?

(A) Mole = Molecular mass / Weight (B) Mole = Weight / Molecular mass

(C) Mole = Weight / Litre (D) Mole = Molecular mass / Litre

(15) What will be the pH of aqueous solution of NH_4 Cl ?

(A) pH = 7 (B) pH > 7 (C) pH < 7 (D) pH = 0

(16) Which of the following solutions will have pH = 2 ?

(A) 0.01 M HCl (B) 0.02 M HCl (C) 0.01M H_2SO_4 (D) 0.02M H_2SO_4

(17) What will be OH^- concentration in aqueous solution having pH = 8 ?

(A) 1×10^{-8} M (B) 1×10^{-6} M (C) 8×10^{-6} M (D) 8×10^{-8} M

(18) If the pH of aqueous solutions A, B, C and D are 1.9, 2.5, 2.1 and 3.0 then what will be the order of acidity ?

(A) A < C < B < D (B) D < C < B < A

(C) D < B < C < A (D) D > C > B > A

(19) Which solution will be basic ?

(A) $[H_3O^+] = 10^{-5}M$ (B) $[H_3O^+] = 10^{-12}M$

(C) $[H_3O^+] = 10^{-7}M$ (D) $[H_3O^+] = 10^{-4}M$