SCIENCE

TEXTBOOK FOR CLASS IX

राष्ट्रीय शैक्षिक अनुसंधान और प्रशिक्षण परिषद्
NATIONAL COUNCIL OF EDUCATIONAL RESEARCH AND TRAINING

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OFFICES OF THE PUBLICATION DIVISION, NCERT

NCERT Campus
Sri Aurobindo Marg
New Delhi 110 016 **Phone : 011-26562708**

108, 100 Feet Road
Hosdakere Halli Extension
Banashankari III Stage
Bangalore 560 085 **Phone : 080-26725740**

Navjivan Trust Building
P.O.Navjivan
Ahmedabad 380 014 **Phone : 079-27541446**

CWC Campus
Opp. Dhankal Bus Stop
Panihati
Kolkata 700 114 **Phone : 033-25530454**

CWC Complex
Maligaon
Guwahati 781 021 **Phone : 0361-2674869**

Publication Team

Head, Publication Division : *Ashok Srivastava*

Chief Production Officer : *Shiv Kumar*

Chief Business Manager : *Gautam Ganguly*

Chief Editor (Contractual Service) : *Naresh Yadav*

Editorial Assistant : *Mathew John*

Production Assistant : *Subodh Srivastava*

Cover
Nidhi Wadhwa

Layout and Illustrations
Digital Expressions

FOREWORD

The National Curriculum Framework (NCF), 2005, recommends that children's life at school must be linked to their life outside the school. This principle marks a departure from the legacy of bookish learning which continues to shape our system and causes a gap between the school, home and community. The syllabi and textbooks developed on the basis of NCF signify an attempt to implement this basic idea. They also attempt to discourage rote learning and the maintenance of sharp boundaries between different subject areas. We hope these measures will take us significantly further in the direction of a child-centred system of education outlined in the National Policy on Education (1986).

The success of this effort depends on the steps that school principals and teachers will take to encourage children to reflect on their own learning and to pursue imaginative activities and questions. We must recognise that, given space, time and freedom, children generate new knowledge by engaging with the information passed on to them by adults. Treating the prescribed textbook as the sole basis of examination is one of the key reasons why other resources and sites of learning are ignored. Inculcating creativity and initiative is possible if we perceive and treat children as participants in learning, not as receivers of a fixed body of knowledge.

These aims imply considerable change in school routines and mode of functioning. Flexibility in the daily time-table is as necessary as rigour in implementing the annual calendar so that the required number of teaching days are actually devoted to teaching. The methods used for teaching and evaluation will also determine how effective this textbook proves for making children's life at school a happy experience, rather than a source of stress or boredom. Syllabus designers have tried to address the problem of curricular burden by restructuring and reorienting knowledge at different stages with greater consideration for child psychology and the time available for teaching. The textbook attempts to enhance this endeavour by giving higher priority and space to opportunities for contemplation and wondering, discussion in small groups, and activities requiring hands-on experience.

The National Council of Educational Research and Training (NCERT) appreciates the hard work done by the textbook development team responsible for this book. We wish to thank the Chairman of the advisory group in science and mathematics, Professor J.V. Narlikar and the Chief Advisor for this book, Professor Rupamanjari Ghosh, School of Physical Sciences, Jawaharlal Nehru University, New Delhi, for guiding the work of this committee. Several teachers contributed to the development of this textbook; we are grateful to them and their principals for making this possible. We are indebted to the institutions and organisations which have generously permitted us to draw upon their resources, material and personnel. We are especially grateful to the members of the National Monitoring Committee, appointed by the Department of Secondary and Higher Education, Ministry of Human Resource Development under the Chairmanship of Professor Mrinal Miri and Professor G.P. Deshpande, for their valuable time and contribution. As an organisation committed to systemic reform and continuous improvement in the quality of its products, NCERT welcomes comments and suggestions which will enable us to undertake further revision and refinement.

Director
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New Delhi
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Chief Advisor

Rupamanjari Ghosh, *Professor*, School of Physical Sciences, Jawaharlal Nehru University, New Delhi

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Uma Sudhir, Eklavya, Indore

Member-Coordinator

Brahm Parkash, *Professor*, DESM, NCERT, New Delhi

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Our National Anthem

Jana-gana-mana adhinayaka, jaya he
Bharata-bhagya-vidhata.
Punjab-Sindh-Gujarat-Maratha
Dravida-Utkala-Banga
Vindhya-Himachala-Yamuna-Ganga
Uchchhala-jaladhi-taranga.
Tava shubha name jage,
Tava shubha asisa mage,
Gahe tava jaya gatha.
Jana-gana-mangala-dayaka jaya he
Bharata-bhagya-vidhata.
Jaya he, jaya he, jaya he,
Jaya jaya jaya, jaya he!

Our National Anthem, composed originally in Bangla by Rabindranath Tagore, was adopted in its Hindi version by the Constituent Assembly as the national anthem of India on 24 January 1950.

Quest for Truth

True education is that which helps us to know the atman, our true self, God and Truth. To acquire this knowledge, some persons may feel the need for a study of literature, some for a study of physical sciences and some others for art. But every branch of knowledge should have as its goal, knowledge of the self. That is so in the Ashram. We carry on numerous activities with that aim in view. All of them are, in my sense of the term, true education. Those activities can also be carried on without any reference to the goal of knowledge of the self. When they are so carried on, they may serve as a means of livelihood or of something else, but they are not education. In an activity carried on as education, a proper understanding of its meaning, devotion to duty and the spirit of service are necessary. The first necessarily brings about development of the intellect. In doing any piece of work, however small, we should be inspired by a holy aim and, while doing it, we should try to understand the purpose which it will serve and the scientific method of doing it. There is a science of every type of work — whether it be cooking, sanitation, carpentry or spinning. Everybody who does his work with the attitude of a student knows its science or discovers it.

— From a microfilm of the Gujarati:
M.M.U./II, 10 July 1932 (CW 50, p. 182)

...We are living in the midst of death, tying to grope our way to Truth. Perhaps it is as well that we are beset with danger at every point in our life, for, inspite of our knowledge of the danger and of our precarious existence, our indifference to the source of all life is excelled only by our amazing arrogance.

....My intellect rebels against the destruction of any life in any shape whatsoever. But my heart is not strong enough to befriend these creatures, which, experience has shown, are destructive. The language of convincing confidence, which comes from actual experience, fails me, and it will continue to do so, so long as I am cowardly enough to fear snakes, tigers and the like.

— *(YI,* 17 July 1927*, p. 222)*

THE CONSTITUTION OF INDIA

PREAMBLE

WE, THE PEOPLE OF INDIA, having solemnly resolved to constitute India into a [1]**[SOVEREIGN SOCIALIST SECULAR DEMOCRATIC REPUBLIC]** and to secure to all its citizens :

JUSTICE, social, economic and political;

LIBERTY of thought, expression, belief, faith and worship;

EQUALITY of status and of opportunity; and to promote among them all

FRATERNITY assuring the dignity of the individual and the [2][unity and integrity of the Nation];

IN OUR CONSTITUENT ASSEMBLY this twenty-sixth day of November, 1949 do **HEREBY ADOPT, ENACT AND GIVE TO OURSELVES THIS CONSTITUTION.**

1. Subs. by the Constitution (Forty-second Amendment) Act, 1976, Sec.2, for "Sovereign Democratic Republic" (w.e.f. 3.1.1977)
2. Subs. by the Constitution (Forty-second Amendment) Act, 1976, Sec.2, for "Unity of the Nation" (w.e.f. 3.1.1977)

Chapter 1

MATTER IN OUR SURROUNDINGS

As we look at our surroundings, we see a large variety of things with different shapes, sizes and textures. Everything in this universe is made up of material which scientists have named "matter". The air we breathe, the food we eat, stones, clouds, stars, plants and animals, even a small drop of water or a particle of sand – every thing is matter. We can also see as we look around that all the things mentioned above occupy space and have mass. In other words, they have both mass* and volume**.

Since early times, human beings have been trying to understand their surroundings. Early Indian philosophers classified matter in the form of five basic elements – the *"Panch Tatva"*– air, earth, fire, sky and water. According to them everything, living or non-living, was made up of these five basic elements. Ancient Greek philosophers had arrived at a similar classification of matter.

Modern day scientists have evolved two types of classification of matter based on their physical properties and chemical nature.

In this chapter we shall learn about matter based on its physical properties. Chemical aspects of matter will be taken up in subsequent chapters.

1.1 Physical Nature of Matter

1.1.1 MATTER IS MADE UP OF PARTICLES

For a long time, two schools of thought prevailed regarding the nature of matter. One school believed matter to be continuous like a block of wood, whereas, the other thought that matter was made up of particles like sand. Let us perform an activity to decide about the nature of matter – is it continuous or particulate?

Activity 1.1

- Take a 100 mL beaker.
- Fill half the beaker with water and mark the level of water.
- Dissolve some salt/ sugar with the help of a glass rod.
- Observe any change in water level.
- What do you think has happened to the salt?
- Where does it disappear?
- Does the level of water change?

In order to answer these questions we need to use the idea that matter is made up of particles. What was there in the spoon, salt or sugar, has now spread throughout water. This is illustrated in Fig. 1.1.

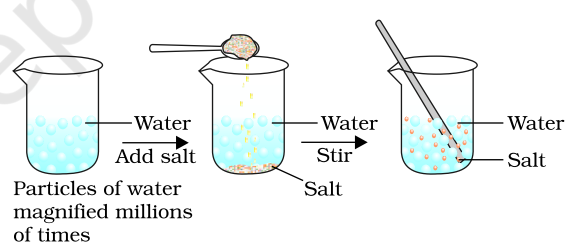

Fig. 1.1: *When we dissolve salt in water, the particles of salt get into the spaces between particles of water.*

1.1.2 HOW SMALL ARE THESE PARTICLES OF MATTER?

Activity 1.2

- Take 2-3 crystals of potassium permanganate and dissolve them in 100 mL of water.

* The SI unit of mass is kilogram (kg).

** The SI unit of volume is cubic metre (m^3). The common unit of measuring volume is litre (L) such that 1L = 1 dm^3, 1L = 1000 mL, 1 mL = 1 cm^3.

- Take out approximately 10 mL of this solution and put it into 90 mL of clear water.
- Take out 10 mL of this solution and put it into another 90 mL of clear water.
- Keep diluting the solution like this 5 to 8 times.
- Is the water still coloured ?

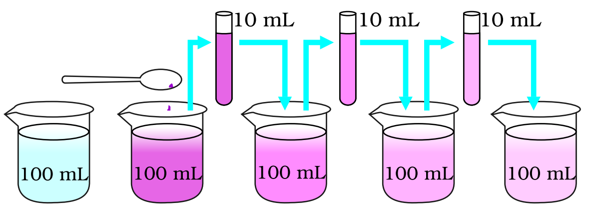

Fig. 1.2: *Estimating how small are the particles of matter. With every dilution, though the colour becomes light, it is still visible.*

This experiment shows that just a few crystals of potassium permanganate can colour a large volume of water (about 1000 L). So we conclude that there must be millions of tiny particles in just one crystal of potassium permanganate, which keep on dividing themselves into smaller and smaller particles.

The same activity can be done using 2 mL of Dettol instead of potassium permanganate. The smell can be detected even on repeated dilution.

> The particles of matter are very small – they are small beyond our imagination!!!!

1.2 Characteristics of Particles of Matter

1.2.1 Particles of matter have space between them

In activities 1.1 and 1.2 we saw that particles of sugar, salt, Dettol, or potassium permanganate got evenly distributed in water. Similarly, when we make tea, coffee or lemonade (*nimbu paani*), particles of one type of matter get into the spaces between particles of the other. This shows that there is enough space between particles of matter.

1.2.2 Particles of matter are continuously moving

Activity 1.3

- Put an unlit incense stick in a corner of your class. How close do you have to go near it so as to get its smell?
- Now light the incense stick. What happens? Do you get the smell sitting at a distance?
- Record your observations.

Activity 1.4

- Take two glasses/beakers filled with water.
- Put a drop of blue or red ink slowly and carefully along the sides of the first beaker and honey in the same way in the second beaker.
- Leave them undisturbed in your house or in a corner of the class.
- Record your observations.
- What do you observe immediately after adding the ink drop?
- What do you observe immediately after adding a drop of honey?
- How many hours or days does it take for the colour of ink to spread evenly throughout the water?

Activity 1.5

- Drop a crystal of copper sulphate or potassium permanganate into a glass of hot water and another containing cold water. Do not stir the solution. Allow the crystals to settle at the bottom.
- What do you observe just above the solid crystal in the glass?
- What happens as time passes?
- What does this suggest about the particles of solid and liquid?
- Does the rate of mixing change with temperature? Why and how?

From the above three activities (1.3, 1.4 and 1.5), we can conclude the following:

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Particles of matter are continuously moving, that is, they possess what we call the kinetic energy. As the temperature rises, particles move faster. So, we can say that with increase in temperature the kinetic energy of the particles also increases.

In the above three activities we observe that particles of matter intermix on their own with each other. They do so by getting into the spaces between the particles. This intermixing of particles of two different types of matter on their own is called diffusion. We also observe that on heating, diffusion becomes faster. Why does this happen?

1.2.3 Particles of matter attract each other

Activity 1.6

- Play this game in the field— make four groups and form human chains as suggested:
- The first group should hold each other from the back and lock arms like Idu-Mishmi dancers (Fig. 1.3).

Fig. 1.3

- The second group should hold hands to form a human chain.
- The third group should form a chain by touching each other with only their finger tips.
- Now, the fourth group of students should run around and try to break the three human chains one by one into as many small groups as possible.
- Which group was the easiest to break? Why?
- If we consider each student as a particle of matter, then in which group the particles held each other with the maximum force?

Activity 1.7

- Take an iron nail, a piece of chalk and a rubber band.
- Try breaking them by hammering, cutting or stretching.
- In which of the above three substances do you think the particles are held together with greater force?

Activity 1.8

- Open a water tap, try breaking the stream of water with your fingers.
- Were you able to cut the stream of water?
- What could be the reason behind the stream of water remaining together?

The above three activities (1.6, 1.7 and 1.8) suggest that particles of matter have force acting between them. This force keeps the particles together. The strength of this force of attraction varies from one kind of matter to another.

Questions

1. *Which of the following are matter?*
   Chair, air, love, smell, hate, almonds, thought, cold, cold-drink, smell of perfume.
2. *Give reasons for the following observation:*
   The smell of hot sizzling food reaches you several metres away, but to get the smell from cold food you have to go close.
3. *A diver is able to cut through water in a swimming pool. Which property of matter does this observation show?*
4. *What are the characteristics of the particles of matter?*

1.3 States of Matter

Observe different types of matter around you. What are its different states? We can see that matter around us exists in three different states– solid, liquid and gas. These states of matter arise due to the variation in the characteristics of the particles of matter.

Now, let us study about the properties of these three states of matter in detail.

1.3.1 The solid state

Activity 1.9

- Collect the following articles— a pen, a book, a needle and a piece of wooden stick.
- Sketch the shape of the above articles in your notebook by moving a pencil around them.
- Do all these have a definite shape, distinct boundaries and a fixed volume?
- What happens if they are hammered, pulled or dropped?
- Are these capable of diffusing into each other?
- Try compressing them by applying force. Are you able to compress them?

All the above are examples of solids. We can observe that all these have a definite shape, distinct boundaries and fixed volumes, that is, have negligible compressibility. Solids have a tendency to maintain their shape when subjected to outside force. Solids may break under force but it is difficult to change their shape, so they are rigid.

Consider the following:

(a) What about a rubber band, can it change its shape on stretching? Is it a solid?

(b) What about sugar and salt? When kept in different jars these take the shape of the jar. Are they solid?

(c) What about a sponge? It is a solid yet we are able to compress it. Why?

All the above are solids as:

- A rubber band changes shape under force and regains the same shape when the force is removed. If excessive force is applied, it breaks.
- The shape of each individual sugar or salt crystal remains fixed, whether we take it in our hand, put it in a plate or in a jar.
- A sponge has minute holes, in which air is trapped, when we press it, the air is expelled out and we are able to compress it.

1.3.2 The liquid state

Activity 1.10

- Collect the following:
  (a) water, cooking oil, milk, juice, a cold drink.
  (b) containers of different shapes. Put a 50 mL mark on these containers using a measuring cylinder from the laboratory.
- What will happen if these liquids are spilt on the floor?
- Measure 50 mL of any one liquid and transfer it into different containers one by one. Does the volume remain the same?
- Does the shape of the liquid remain the same ?
- When you pour the liquid from one container into another, does it flow easily?

We observe that liquids have no fixed shape but have a fixed volume. They take up the shape of the container in which they are kept. Liquids flow and change shape, so they are not rigid but can be called fluid.

Refer to activities 1.4 and 1.5 where we saw that solids and liquids can diffuse into liquids. The gases from the atmosphere diffuse and dissolve in water. These gases, especially oxygen and carbon dioxide, are essential for the survival of aquatic animals and plants.

All living creatures need to breathe for survival. The aquatic animals can breathe under water due to the presence of dissolved oxygen in water. Thus, we may conclude that solids, liquids and gases can diffuse into liquids. The rate of diffusion of liquids is

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higher than that of solids. This is due to the fact that in the liquid state, particles move freely and have greater space between each other as compared to particles in the solid state.

1.3.3 The gaseous state

Have you ever observed a balloon seller filling a large number of balloons from a single cylinder of gas? Enquire from him how many balloons is he able to fill from one cylinder. Ask him which gas does he have in the cylinder.

Activity 1.11

- Take three 100 mL syringes and close their nozzles by rubber corks, as shown in Fig.1.4.
- Remove the pistons from all the syringes.
- Leaving one syringe untouched, fill water in the second and pieces of chalk in the third.
- Insert the pistons back into the syringes. You may apply some vaseline on the pistons before inserting them into the syringes for their smooth movement.
- Now, try to compress the content by pushing the piston in each syringe.

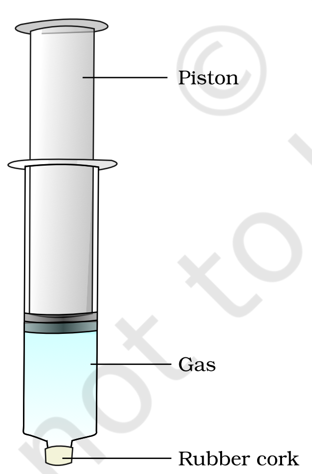

Fig. 1.4

- What do you observe? In which case was the piston easily pushed in?
- What do you infer from your observations?

We have observed that gases are highly compressible as compared to solids and liquids. The liquefied petroleum gas (LPG) cylinder that we get in our home for cooking or the oxygen supplied to hospitals in cylinders is compressed gas. Compressed natural gas (CNG) is used as fuel these days in vehicles. Due to its high compressibility, large volumes of a gas can be compressed into a small cylinder and transported easily.

We come to know of what is being cooked in the kitchen without even entering there, by the smell that reaches our nostrils. How does this smell reach us? The particles of the aroma of food mix with the particles of air spread from the kitchen, reach us and even farther away. The smell of hot cooked food reaches us in seconds; compare this with the rate of diffusion of solids and liquids. Due to high speed of particles and large space between them, gases show the property of diffusing very fast into other gases.

In the gaseous state, the particles move about randomly at high speed. Due to this random movement, the particles hit each other and also the walls of the container. The pressure exerted by the gas is because of this force exerted by gas particles per unit area on the walls of the container.

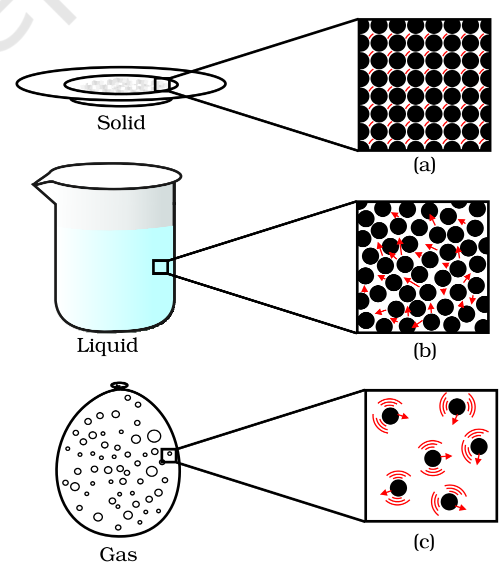

Fig.1.5: *a, b and c show the magnified schematic pictures of the three states of matter. The motion of the particles can be seen and compared in the three states of matter.*

Questions

1. *The mass per unit volume of a substance is called density. (density = mass/volume). Arrange the following in order of increasing density – air, exhaust from chimneys, honey, water, chalk, cotton and iron.*
2. *(a) Tabulate the differences in the characterisitcs of states of matter.*
   (b) Comment upon the following: rigidity, compressibility, fluidity, filling a gas container, shape, kinetic energy and density.
3. *Give reasons*
   (a) A gas fills completely the vessel in which it is kept.
   (b) A gas exerts pressure on the walls of the container.
   (c) A wooden table should be called a solid.
   (d) We can easily move our hand in air but to do the same through a solid block of wood we need a karate expert.
4. *Liquids generally have lower density as compared to solids. But you must have observed that ice floats on water. Find out why.*

1.4 Can Matter Change its State?

We all know from our observation that water can exist in three states of matter–

- solid, as ice,
- liquid, as the familiar water, and
- gas, as water vapour.

What happens inside the matter during this change of state? What happens to the particles of matter during the change of states? How does this change of state take place? We need answers to these questions, isn't it?

1.4.1 Effect of change of temperature

Activity _____________ 1.12

- Take about 150 g of ice in a beaker and suspend a laboratory thermometer so that its bulb is in contact with the ice, as in Fig. 1.6.

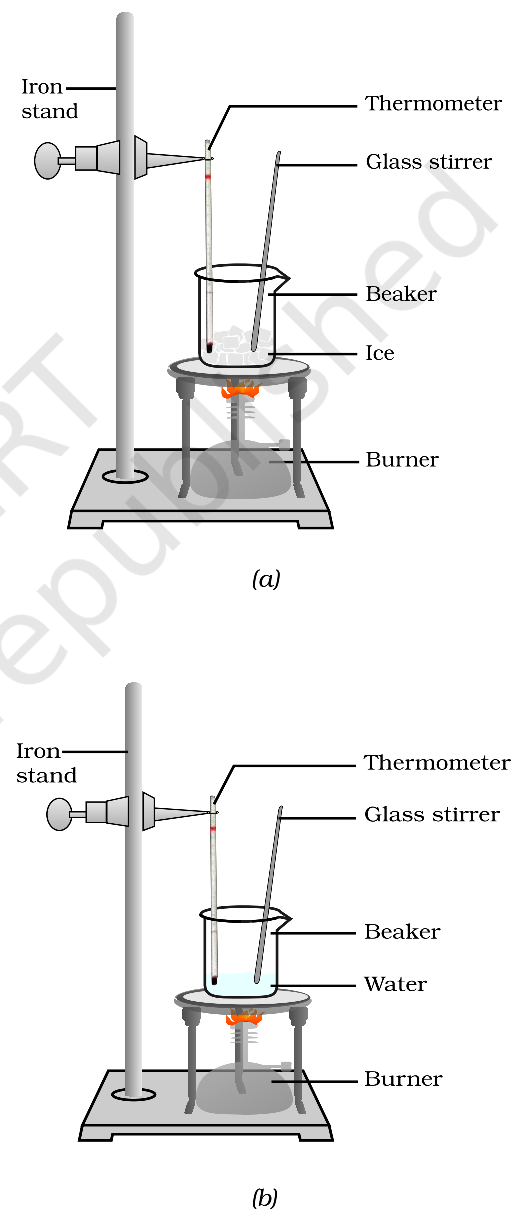

Fig. 1.6: *(a) Conversion of ice to water, (b) conversion of water to water vapour*

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- Start heating the beaker on a low flame.
- Note the temperature when the ice starts melting.
- Note the temperature when all the ice has converted into water.
- Record your observations for this conversion of solid to liquid state.
- Now, put a glass rod in the beaker and heat while stirring till the water starts boiling.
- Keep a careful eye on the thermometer reading till most of the water has vaporised.
- Record your observations for the conversion of water in the liquid state to the gaseous state.

On increasing the temperature of solids, the kinetic energy of the particles increases. Due to the increase in kinetic energy, the particles start vibrating with greater speed. The energy supplied by heat overcomes the forces of attraction between the particles. The particles leave their fixed positions and start moving more freely. A stage is reached when the solid melts and is converted to a liquid. The temperature at which a solid melts to become a liquid at the atmospheric pressure is called its melting point.

> The melting point of a solid is an indication of the strength of the force of attraction between its particles.

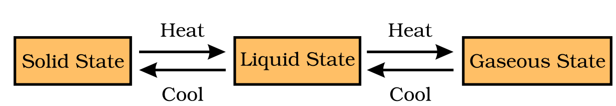
The melting point of ice is 273.16 K*. The process of melting, that is, change of solid state into liquid state is also known as fusion. ***When a solid melts, its temperature remains the same, so where does the heat energy go?***

You must have observed, during the experiment of melting, that the temperature of the system does not change after the melting point is reached, till all the ice melts. This happens even though we continue to heat the beaker, that is, we continue to supply heat. This heat gets used up in changing the state by overcoming the forces of attraction between the particles. As this heat energy is absorbed by ice without showing any rise in temperature, it is considered that it gets hidden into the contents of the beaker and is known as the latent heat. The word latent means hidden. The amount of heat energy that is required to change 1 kg of a solid into liquid at atmospheric pressure at its melting point is known as the latent heat of fusion. So, particles in water at 0^0 C (273 K) have more energy as compared to particles in ice at the same temperature.

When we supply heat energy to water, particles start moving even faster. At a certain temperature, a point is reached when the particles have enough energy to break free from the forces of attraction of each other. At this temperature the liquid starts changing into gas. The temperature at which a liquid starts boiling at the atmospheric pressure is known as its boiling point. Boiling is a bulk phenomenon. Particles from the bulk of the liquid gain enough energy to change into the vapour state.

For water this temperature is 373 K ($100\ ^0$C = 273 + 100 = 373 K).

Can you define the latent heat of vaporisation? Do it in the same way as we have defined the latent heat of fusion. Particles in steam, that is, water vapour at 373 K (100^0 C) have more energy than water at the same temperature. This is because particles in steam have absorbed extra energy in the form of latent heat of vaporisation.



So, we infer that the state of matter can be changed into another state by changing the temperature.

We have learnt that substances around us change state from solid to liquid and from liquid to gas on application of heat. But there

*__Note:__ *Kelvin* is the SI unit of temperature, 0^0 C =273.16 K. For convenience, we take 0^0 C = 273 K after rounding off the decimal. To change a temperature on the Kelvin scale to the Celsius scale you have to subtract 273 from the given temperature, and to convert a temperature on the Celsius scale to the Kelvin scale you have to add 273 to the given temperature.

are some that change directly from solid state to gaseous state and vice versa without changing into the liquid state.

Activity _____________ *1.13*

- Take some camphor or ammonium chloride. Crush it and put it in a china dish.
- Put an inverted funnel over the china dish.
- Put a cotton plug on the stem of the funnel, as shown in Fig. 1.7.

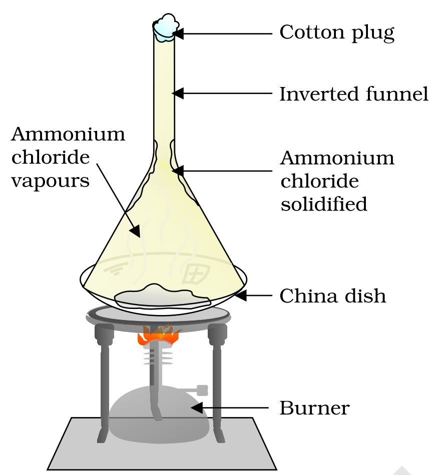


Fig. 1.7: *Sublimation of ammonium chloride*

- Now, heat slowly and observe.
- What do you infer from the above activity?

A change of state directly from solid to gas without changing into liquid state (or vice versa) is called sublimation.

1.4.2 Effect of Change of Pressure

We have already learnt that the difference in various states of matter is due to the difference in the distances between the constituent particles. What will happen when we start putting pressure and compress a gas enclosed in a cylinder? Will the particles come closer? Do you think that increasing or decreasing the pressure can change the state of matter?

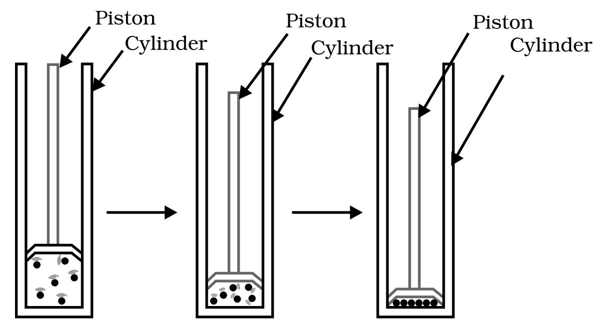


Fig. 1.8: *By applying pressure, particles of matter can be brought close together.*

Applying pressure and reducing temperature can liquefy gases.

Have you heard of solid carbon dioxide (CO_2)? It is stored under high pressure. Solid CO_2 gets converted directly to gaseous state on decrease of pressure to 1 atmosphere* without coming into liquid state. This is the reason that solid carbon dioxide is also known as dry ice.

Thus, we can say that pressure and temperature determine the state of a substance, whether it will be solid, liquid or gas.

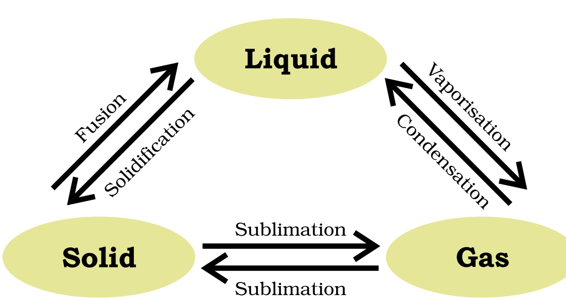


Fig. 1.9: *Interconversion of the three states of matter*

* *atmosphere (atm)* is a unit of measuring pressure exerted by a gas. The unit of pressure is Pascal (Pa): 1 atmosphere = 1.01 × 10^5 Pa. The pressure of air in atmosphere is called atmospheric pressure. The atmospheric pressure at sea level is 1 atmosphere, and is taken as the normal atmospheric pressure.

Questions

1. *Convert the following temperature to celsius scale:*
   a. 300 K b. 573 K.
2. *What is the physical state of water at:*
   a. 250ºC b. 100ºC ?
3. *For any substance, why does the temperature remain constant during the change of state?*
4. *Suggest a method to liquefy atmospheric gases.*

1.5 Evaporation

Do we always need to heat or change pressure for changing the state of matter? Can you quote some examples from everyday life where change of state from liquid to vapour takes place without the liquid reaching the boiling point? Water, when left uncovered, slowly changes into vapour. Wet clothes dry up. What happens to water in the above two examples?

We know that particles of matter are always moving and are never at rest. At a given temperature in any gas, liquid or solid, there are particles with different amounts of kinetic energy. In the case of liquids, a small fraction of particles at the surface, having higher kinetic energy, is able to break away from the forces of attraction of other particles and gets converted into vapour. This phenomenon of change of a liquid into vapours at any temperature below its boiling point is called evaporation.

1.5.1 Factors affecting evaporation

Let us understand this with an activity.

Activity 1.14

- Take 5 mL of water in a test tube and keep it near a window or under a fan.
- Take 5 mL of water in an open china dish and keep it near a window or under a fan.
- Take 5 mL of water in an open china dish and keep it inside a cupboard or on a shelf in your class.
- Record the room temperature.
- Record the time or days taken for the evaporation process in the above cases.
- Repeat the above three steps of activity on a rainy day and record your observations.
- What do you infer about the effect of temperature, surface area and wind velocity (speed) on evaporation?

You must have observed that the rate of evaporation increases with–

- an increase of surface area:
  We know that evaporation is a surface phenomenon. If the surface area is increased, the rate of evaporation increases. For example, while putting clothes for drying up we spread them out.
- an increase of temperature:
  With the increase of temperature, more number of particles get enough kinetic energy to go into the vapour state.
- a decrease in humidity:
  Humidity is the amount of water vapour present in air. The air around us cannot hold more than a definite amount of water vapour at a given temperature. If the amount of water in air is already high, the rate of evaporation decreases.
- an increase in wind speed:
  It is a common observation that clothes dry faster on a windy day. With the increase in wind speed, the particles of water vapour move away with the wind, decreasing the amount of water vapour in the surrounding.

1.5.2 How does evaporation cause cooling?

In an open vessel, the liquid keeps on evaporating. The particles of liquid absorb energy from the surrounding to regain the energy lost during evaporation. This absorption of energy from the surroundings make the surroundings cold.

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What happens when you pour some acetone (nail polish remover) on your palm? The particles gain energy from your palm or surroundings and evaporate causing the palm to feel cool.

After a hot sunny day, people sprinkle water on the roof or open ground because the large latent heat of vaporisation of water helps to cool the hot surface.

Can you cite some more examples from daily life where we can feel the effect of cooling due to evaporation?

Why should we wear cotton clothes in summer?

During summer, we perspire more because of the mechanism of our body which keeps us cool. We know that during evaporation, the particles at the surface of the liquid gain energy from the surroundings or body surface and change into vapour. The heat energy equal to the latent heat of vaporisation is absorbed from the body leaving the body cool. Cotton, being a good absorber of water helps in absorbing the sweat and exposing it to the atmosphere for easy evaporation.

Why do we see water droplets on the outer surface of a glass containing ice-cold water?

Let us take some ice-cold water in a tumbler. Soon we will see water droplets on the outer surface of the tumbler. The water vapour present in air, on coming in contact with the cold glass of water, loses energy and gets converted to liquid state, which we see as water droplets.

Questions

1. *Why does a desert cooler cool better on a hot dry day?*
2. *How does the water kept in an earthen pot (matka) become cool during summer?*
3. *Why does our palm feel cold when we put some acetone or petrol or perfume on it?*
4. *Why are we able to sip hot tea or milk faster from a saucer rather than a cup?*
5. *What type of clothes should we wear in summer?*

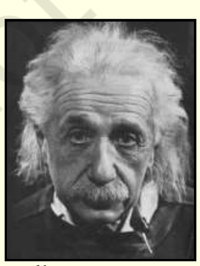
More to know

Now scientists are talking of five states of matter: Solid, Liquid, Gas, Plasma and Bose-Einstein Condensate.

Plasma: The state consists of super energetic and super excited particles. These particles are in the form of ionised gases. The fluorescent tube and neon sign bulbs consist of plasma. Inside a neon sign bulb there is neon gas and inside a fluorescent tube there is helium gas or some other gas. The gas gets ionised, that is, gets charged when electrical energy flows through it. This charging up creates a plasma glowing inside the tube or bulb. The plasma glows with a special colour depending on the nature of gas. The Sun and the stars glow because of the presence of plasma in them. The plasma is created in stars because of very high temperature.

Bose-Einstein Condensate: In 1920, Indian physicist Satyendra Nath Bose had done some calculations for a fifth state of matter. Building on his calculations, Albert Einstein predicted a new state of matter – the Bose-Einstein Condensate (BEC). In 2001, Eric A. Cornell, Wolfgang Ketterle and Carl E. Wieman of USA received the Nobel prize in physics for achieving "Bose-Einstein condensation". The BEC is formed by cooling a gas of extremely low density, about one-hundred-thousandth the density of normal air, to super low temperatures. You can log on to www.chem4kids.com to get more information on these fourth and fifth states of matter.

S.N. Bose (1894-1974)



Albert Einstein (1879-1955)

What you have learnt

- Matter is made up of small particles.
- The matter around us exists in three states— solid, liquid and gas.
- The forces of attraction between the particles are maximum in solids, intermediate in liquids and minimum in gases.
- The spaces in between the constituent particles and kinetic energy of the particles are minimum in the case of solids, intermediate in liquids and maximum in gases.
- The arrangement of particles is most ordered in the case of solids, in the case of liquids layers of particles can slip and slide over each other while for gases, there is no order, particles just move about randomly.
- The states of matter are inter-convertible. The state of matter can be changed by changing temperature or pressure.
- Sublimation is the change of gaseous state directly to solid state without going through liquid state, and vice versa.
- Boiling is a bulk phenomenon. Particles from the bulk (whole) of the liquid change into vapour state.
- Evaporation is a surface phenomenon. Particles from the surface gain enough energy to overcome the forces of attraction present in the liquid and change into the vapour state.
- The rate of evaporation depends upon the surface area exposed to the atmosphere, the temperature, the humidity and the wind speed.
- Evaporation causes cooling.
- Latent heat of vaporisation is the heat energy required to change 1 kg of a liquid to gas at atmospheric pressure at its boiling point.
- Latent heat of fusion is the amount of heat energy required to change 1 kg of solid into liquid at its melting point.

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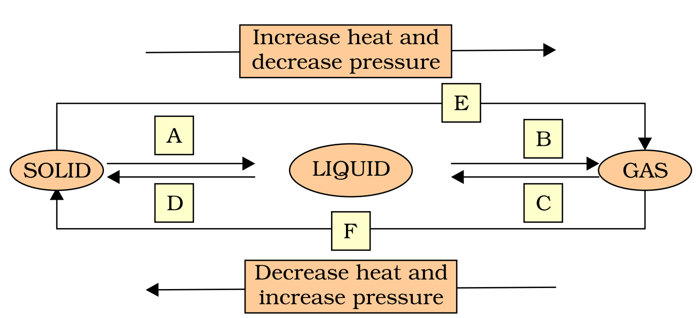
- Some measurable quantities and their units to remember:

Quantity	Unit	Symbol
Temperature	kelvin	K
Length	metre	m
Mass	kilogram	kg
Weight	newton	N
Volume	cubic metre	m^3
Density	kilogram per cubic metre	$kg\ m^{-3}$
Pressure	pascal	Pa

Exercises

1. Convert the following temperatures to the celsius scale.
   (a) 293 K (b) 470 K.
2. Convert the following temperatures to the Kelvin scale.
   (a) 25°C (b) 373°C.
3. Give reason for the following observations.
   (a) Naphthalene balls disappear with time without leaving any solid.
   (b) We can get the smell of perfume sitting several metres away.
4. Arrange the following substances in increasing order of forces of attraction between the particles— water, sugar, oxygen.
5. What is the physical state of water at—
   (a) 25°C (b) 0°C (c) 100°C ?
6. Give two reasons to justify—
   (a) water at room temperature is a liquid.
   (b) an iron almirah is a solid at room temperature.
7. Why is ice at 273 K more effective in cooling than water at the same temperature?
8. What produces more severe burns, boiling water or steam?
9. Name A,B,C,D,E and F in the following diagram showing change in its state



Group Activity

Prepare a model to demonstrate movement of particles in solids, liquids and gases.

For making this model you will need

- A transparent jar
- A big rubber balloon or piece of stretchable rubber sheet
- A string
- Few chick-peas or black gram or dry green peas.

How to make?

- Put the seeds in the jar.
- Sew the string to the centre of the rubber sheet and put some tape to keep it tied securely.
- Stretch and tie the rubber sheet on the mouth of the jar.
- Your model is ready. Now run your fingers up and down the string by first tugging at it slowly and then rapidly.

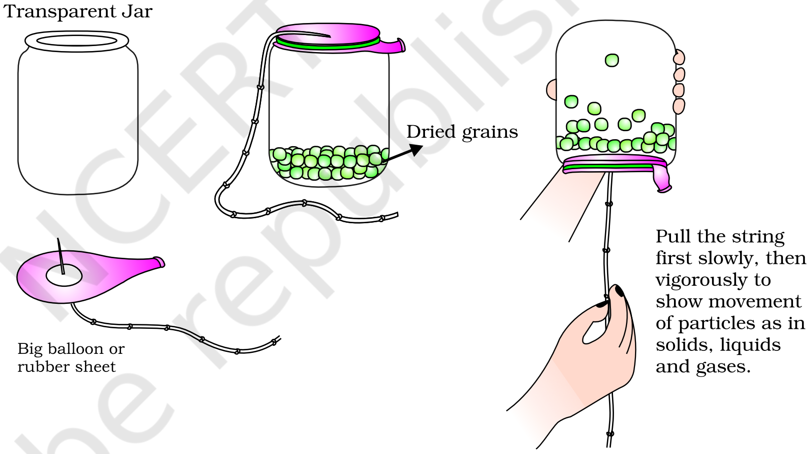


Fig. 1.10: *A model for happy converting of solid to liquid and liquid to gas.*

Chapter 2

IS MATTER AROUND US PURE

How do we judge whether milk, ghee, butter, salt, spices, mineral water or juice that we buy from the market are pure?

Fig. 2.1: *Some consumable items*

Have you ever noticed the word 'pure' written on the packs of these consumables? For a common person pure means having no adulteration. But, for a scientist all these things are actually mixtures of different substances and hence not pure. For example, milk is actually a mixture of water, fat, proteins etc. When a scientist says that something is pure, it means that all the constituent particles of that substance are the same in their chemical nature. A pure substance consists of a single type of particles. In other words, a substance is a pure single form of matter.

As we look around, we can see that most of the matter around us exist as mixtures of two or more pure components, for example, sea water, minerals, soil etc. are all mixtures.

2.1 What is a Mixture?

Mixtures are constituted by more than one kind of pure form of matter, known as a substance. A substance cannot be separated into other kinds of matter by any physical process. We know that dissolved sodium chloride can be separated from water by the physical process of evaporation. However, sodium chloride is itself a substance and cannot be separated by physical process into its chemical constituents. Similarly, sugar is a substance because it contains only one kind of pure matter and its composition is the same throughout.

Soft drink and soil are not single substances. Whatever the source of a substance may be, it will always have the same characteristic properties.

Therefore, we can say that a mixture contains more than one substance.

2.1.1 TYPES OF MIXTURES

Depending upon the nature of the components that form a mixture, we can have different types of mixtures.

Activity 2.1

- Let us divide the class into groups A, B, C and D.
- Group A takes a beaker containing 50 mL of water and one spatula full of copper sulphate powder. Group B takes 50 mL of water and two spatula full of copper sulphate powder in a beaker.
- Groups C and D can take different amounts of copper sulphate and potassium permanganate or common salt (sodium chloride) and mix the given components to form a mixture.
- Report the observations on the uniformity in colour and texture.
- Groups A and B have obtained a mixture which has a uniform composition throughout. Such mixtures are called homogeneous mixtures or solutions. Some other examples of such mixtures are: (i) salt

in water and (ii) sugar in water. Compare the colour of the solutions of the two groups. Though both the groups have obtained copper sulphate solution but the intensity of colour of the solutions is different. This shows that a homogeneous mixture can have a variable composition.

- Groups C and D have obtained mixtures, which contain physically distinct parts and have non-uniform compositions. Such mixtures are called heterogeneous mixtures. Mixtures of sodium chloride and iron filings, salt and sulphur, and oil and water are examples of heterogeneous mixtures.

Activity 2.2

- Let us again divide the class into four groups – A, B, C and D.
- Distribute the following samples to each group:
  - Few crystals of copper sulphate to group A.
  - One spatula full of copper sulphate to group B.
  - Chalk powder or wheat flour to group C.
  - Few drops of milk or ink to group D.
- Each group should add the given sample in water and stir properly using a glass rod. Are the particles in the mixture visible?
- Direct a beam of light from a torch through the beaker containing the mixture and observe from the front. Was the path of the beam of light visible?
- Leave the mixtures undisturbed for a few minutes (and set up the filtration apparatus in the meantime). Is the mixture stable or do the particles begin to settle after some time?
- Filter the mixture. Is there any residue on the filter paper?

Discuss the results and form an opinion.

- *Groups A and B have got a solution.*
- *Group C has got a suspension.*
- *Group D has got a colloidal solution.*

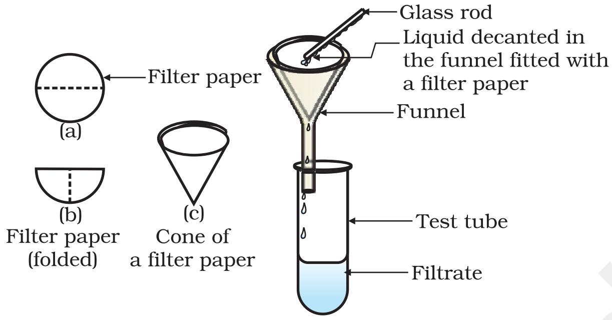


Fig. 2.2: *Filtration*

Now, we shall learn about solutions, suspensions and colloidal solutions in the following sections.

Questions

1. *What is meant by a substance?*
2. *List the points of differences between homogeneous and heterogeneous mixtures.*

2.2 What is a Solution?

A solution is a homogeneous mixture of two or more substances. You come across various types of solutions in your daily life. Lemonade, soda water etc. are all examples of solutions. Usually we think of a solution as a liquid that contains either a solid, liquid or a gas dissolved in it. But, we can also have solid solutions (alloys) and gaseous solutions (air). In a solution there is homogeneity at the particle level. For example, lemonade tastes the same throughout. This shows that particles of sugar or salt are evenly distributed in the solution.

More to know

Alloys: Alloys are mixtures of two or more metals or a metal and a non-metal and cannot be separated into their components by physical methods. But still, an alloy is considered as a mixture because it shows the properties of its constituents and can have variable composition. For example, brass is a mixture of approximately 30% zinc and 70% copper.

A solution has a solvent and a solute as its components. The component of the solution that dissolves the other component in it (usually the component present in larger amount) is called the solvent. The component of the solution that is dissolved in the solvent (usually present in lesser quantity) is called the solute.

Examples:

(i) A solution of sugar in water is a solid in liquid solution. In this solution, sugar is the solute and water is the solvent.

(ii) A solution of iodine in alcohol known as 'tincture of iodine', has iodine (solid) as the solute and alcohol (liquid) as the solvent.

(iii) Aerated drinks like soda water etc., are gas in liquid solutions. These contain carbon dioxide (gas) as solute and water (liquid) as solvent.

(iv) Air is a mixture of gas in gas. Air is a homogeneous mixture of a number of gases. Its two main constituents are: oxygen (21%) and nitrogen (78%). The other gases are present in very small quantities.

Properties of a solution

- A solution is a homogeneous mixture.
- The particles of a solution are smaller than 1 nm (10^{-9} metre) in diameter. So, they cannot be seen by naked eyes.
- Because of very small particle size, they do not scatter a beam of light passing through the solution. So, the path of light is not visible in a solution.
- The solute particles cannot be separated from the mixture by the process of filtration. The solute particles do not settle down when left undisturbed, that is, a solution is stable.

2.2.1 CONCENTRATION OF A SOLUTION

In activity 2.2, we observed that groups A and B obtained different shades of solutions. So, we understand that in a solution the relative proportion of the solute and solvent can be varied. Depending upon the amount of solute present in a solution, it can be called a dilute, concentrated or a saturated solution. Dilute and concentrated are comparative terms. In activity 2.2, the solution obtained by group A is dilute as compared to that obtained by group B.

Activity 2.3

- Take approximately 50 mL of water each in two separate beakers.
- Add salt in one beaker and sugar or barium chloride in the second beaker with continuous stirring.
- When no more solute can be dissolved, heat the contents of the beaker to raise the temperature by about 5°C.
- Start adding the solute again.

Is the amount of salt and sugar or barium chloride, that can be dissolved in water at a given temperature, the same?

At any particular temperature, a solution that has dissolved as much solute as it is capable of dissolving, is said to be a saturated solution. In other words, when no more solute can be dissolved in a solution at a given temperature, it is called a saturated solution. The amount of the solute present in the saturated solution at this temperature is called its solubility.

If the amount of solute contained in a solution is less than the saturation level, it is called an unsaturated solution.

What would happen if you were to take a saturated solution at a certain temperature and cool it slowly.

We can infer from the above activity that different substances in a given solvent have different solubilities at the same temperature.

The concentration of a solution is the amount of solute present in a given amount (mass or volume) of solution, or the amount of solute dissolved in a given mass or volume of solvent.

Concentration of solution = Amount of solute/Amount of solution

Or

Amount of solute/Amount of solvent

There are various ways of expressing the concentration of a solution, but here we will learn only two methods.

(i) Mass by mass percentage of a solution

$$= \frac{\text{Mass of solute}}{\text{Mass of solution}} \times 100$$

(ii) Mass by volume percentage of a solution

$$= \frac{\text{Mass of solute}}{\text{Volume of solution}} \times 100$$

Example 2.1 A solution contains 40 g of common salt in 320 g of water. Calculate the concentration in terms of mass by mass percentage of the solution.

Solution:

Mass of solute (salt) = 40 g
Mass of solvent (water) = 320 g

We know,

Mass of solution = Mass of solute + Mass of solvent
= 40 g + 320 g
= 360 g

Mass percentage of solution

$$= \frac{\text{Mass of solute}}{\text{Mass of solution}} \times 100$$

$$= \frac{40}{360} \times 100 = 11.1\%$$

2.2.2 What is a suspension?

Non-homogeneous systems, like those obtained by group C in activity 2.2, in which solids are dispersed in liquids, are called suspensions. A suspension is a heterogeneous mixture in which the solute particles do not dissolve but remain suspended throughout the bulk of the medium. Particles of a suspension are visible to the naked eye.

Properties of a Suspension

- Suspension is a heterogeneous mixture.
- The particles of a suspension can be seen by the naked eye.
- The particles of a suspension scatter a beam of light passing through it and make its path visible.
- The solute particles settle down when a suspension is left undisturbed, that is, a suspension is unstable. They can be separated from the mixture by the process of filtration. When the particles settle down, the suspension breaks and it does not scatter light any more.

2.2.3 What is a colloidal solution?

The mixture obtained by group D in activity 2.2 is called a colloid or a colloidal solution. The particles of a colloid are uniformly spread throughout the solution. Due to the relatively smaller size of particles, as compared to that of a suspension, the mixture appears to be homogeneous. But actually, a colloidal solution is a heterogeneous mixture, for example, milk.

Because of the small size of colloidal particles, we cannot see them with naked eyes. But, these particles can easily scatter a beam of visible light as observed in activity 2.2. This scattering of a beam of light is called the Tyndall effect after the name of the scientist who discovered this effect.

Tyndall effect can also be observed when a fine beam of light enters a room through a small hole. This happens due to the scattering of light by the particles of dust and smoke in the air.

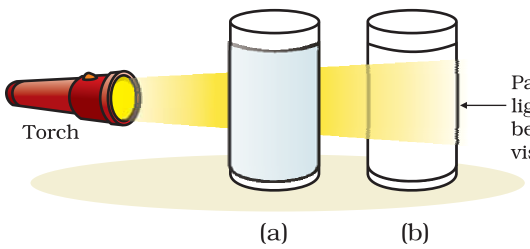


Fig. 2.3: (a) Solution of copper sulphate does not show Tyndall effect, (b) mixture of water and milk shows Tyndall effect.

Tyndall effect can be observed when sunlight passes through the canopy of a dense forest. In the forest, mist contains tiny droplets of water, which act as particles of colloid dispersed in air.

Fig. 2.4: *The Tyndall effect*

Properties of a colloid

- A colloid is a heterogeneous mixture.
- The size of particles of a colloid is too small to be individually seen by naked eyes.
- Colloids are big enough to scatter a beam of light passing through it and make its path visible.
- They do not settle down when left undisturbed, that is, a colloid is quite stable.
- They cannot be separated from the mixture by the process of filtration. But, a special technique of separation known as centrifugation (perform activity 2.5), can be used to separate the colloidal particles.

The components of a colloidal solution are the dispersed phase and the dispersion medium. The solute-like component or the dispersed particles in a colloid form the dispersed phase, and the component in which the dispersed phase is suspended is known as the dispersing medium. Colloids are classified according to the state (solid, liquid or gas) of the dispersing medium and the dispersed phase. A few common examples are given in Table 2.1. From this table you can see that they are very common everyday life.

Questions

1. *Differentiate between homogeneous and heterogeneous mixtures with examples.*
2. *How are sol, solution and suspension different from each other?*
3. *To make a saturated solution, 36 g of sodium chloride is dissolved in 100 g of water at 293 K. Find its concentration at this temperature.*

Table 2.1: Common examples of colloids

Dispersed phase	Dispersing Medium	Type	Example
Liquid	Gas	Aerosol	Fog, clouds, mist
Solid	Gas	Aerosol	Smoke, automobile exhaust
Gas	Liquid	Foam	Shaving cream
Liquid	Liquid	Emulsion	Milk, face cream
Solid	Liquid	Sol	Milk of magnesia, mud
Gas	Solid	Foam	Foam, rubber, sponge, pumice
Liquid	Solid	Gel	Jelly, cheese, butter
Solid	Solid	Solid Sol	Coloured gemstone, milky glass

2.3 Separating the Components of a Mixture

We have learnt that most of the natural substances are not chemically pure. Different methods of separation are used to get individual components from a mixture. Separation makes it possible to study and use the individual components of a mixture.

Heterogeneous mixtures can be separated into their respective constituents by simple physical methods like handpicking, sieving, filtration that we use in our day-to-day life. Sometimes special techniques have to be used for the separation of the components of a mixture.

2.3.1 How can we obtain coloured component (dye) from blue/black ink?

Activity 2.4

- Fill half a beaker with water.
- Put a watch glass on the mouth of the beaker (Fig. 2.5).
- Put few drops of ink on the watch glass.
- Now start heating the beaker. We do not want to heat the ink directly. You will see that evaporation is taking place from the watch glass.
- Continue heating as the evaporation goes on and stop heating when you do not see any further change on the watch glass.
- Observe carefully and record your observations.

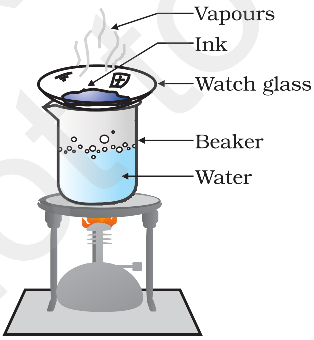


Fig. 2.5: *Evaporation*

Now answer

- *What do you think has got evaporated from the watch glass?*
- *Is there a residue on the watch glass?*
- *What is your interpretation? Is ink a single substance (pure) or is it a mixture?*

We find that ink is a mixture of a dye in water. Thus, we can separate the volatile component (solvent) from its non-volatile solute by the method of evaporation.

2.3.2 How can we separate cream from milk?

Now-a-days, we get full-cream, toned and double-toned varieties of milk packed in poly-packs or tetra packs in the market. These varieties of milk contain different amounts of fat.

Activity 2.5

- Take some full-cream milk in a test tube.
- Centrifuge it by using a centrifuging machine for two minutes. If a centrifuging machine is not available in the school, you can do this activity at home by using a milk churner, used in the kitchen.
- If you have a milk dairy nearby, visit it and ask (i) how they separate cream from milk and (ii) how they make cheese (*paneer*) from milk.

Now answer

- *What do you observe on churning the milk?*
- *Explain how the separation of cream from milk takes place.*

Sometimes the solid particles in a liquid are very small and pass through a filter paper. For such particles the filtration technique cannot be used for separation. Such mixtures are separated by centrifugation. The principle is that the denser particles are forced to the bottom and the lighter particles stay at the top when spun rapidly.

Applications

- Used in diagnostic laboratories for blood and urine tests.
- Used in dairies and home to separate butter from cream.
- Used in washing machines to squeeze out water from wet clothes.

2.3.3 How can we separate a mixture of two immiscible liquids?

Activity 2.6

- Let us try to separate kerosene oil from water using a separating funnel.
- Pour the mixture of kerosene oil and water in a separating funnel (Fig. 2.6).
- Let it stand undisturbed for sometime so that separate layers of oil and water are formed.
- Open the stopcock of the separating funnel and pour out the lower layer of water carefully.
- Close the stopcock of the separating funnel as the oil reaches the stop-cock.

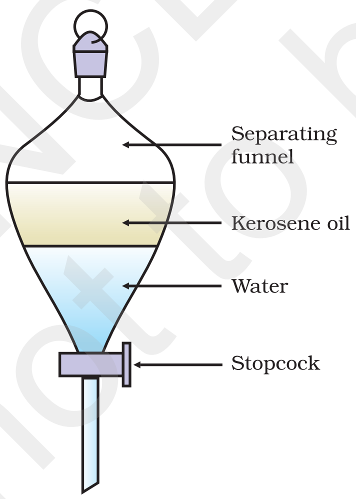


Fig. 2.6: *Separation of immiscible liquids*

Applications

- To separate mixture of oil and water.
- In the extraction of iron from its ore, the lighter slag is removed from the top by this method to leave the molten iron at the bottom in the furnace.

The principle is that immiscible liquids separate out in layers depending on their densities.

2.3.4 How can we separate a mixture of salt and ammonium chloride?

We have learnt in chapter 1 that ammonium chloride changes directly from solid to gaseous state on heating. So, to separate such mixtures that contain a sublimable volatile component from a non-sublimable impurity (salt in this case), the sublimation process is used (Fig. 2.7). Some examples of solids which sublime are ammonium chloride, camphor, naphthalene and anthracene.

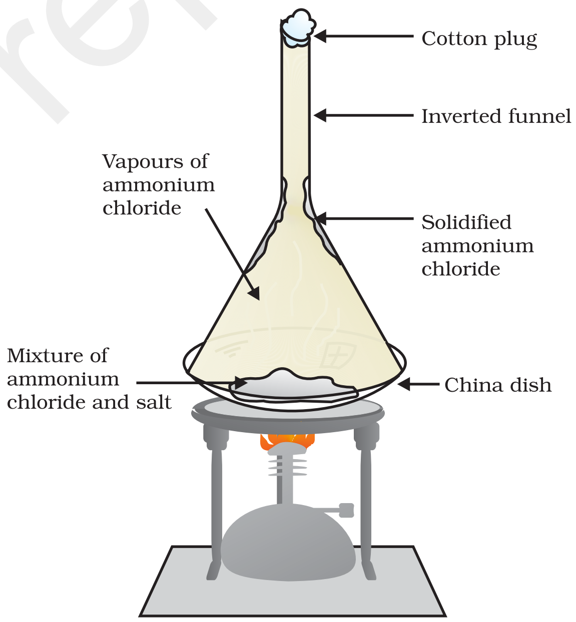


Fig. 2.7: *Separation of ammonium chloride and salt by sublimation*

2.3.5 Is the dye in black ink a single colour?

Activity 2.7

- Take a thin strip of filter paper.
- Draw a line on it using a pencil, approximately 3 cm above the lower edge [Fig. 2.8 (a)].
- Put a small drop of ink (water soluble, that is, from a sketch pen or fountain pen) at the centre of the line. Let it dry.
- Lower the filter paper into a jar/glass/beaker/test tube containing water so that the drop of ink on the paper is just above the water level, as shown in Fig. 2.8(b) and leave it undisturbed.
- Watch carefully, as the water rises up on the filter paper. Record your observations.

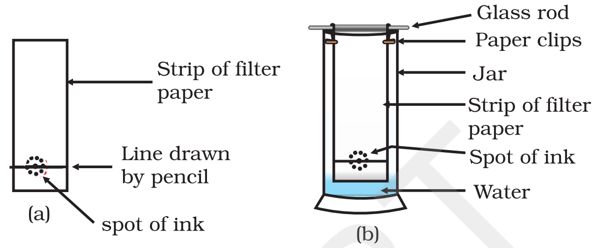


Fig. 2.8: *Separation of dyes in black ink using chromatography*

Now answer

- *What do you observe on the filter paper as the water rises on it?*
- *Do you obtain different colours on the filter paper strip?*
- *What according to you, can be the reason for the rise of the coloured spot on the paper strip?*

The ink that we use has water as the solvent and the dye is soluble in it. As the water rises on the filter paper it takes along with it the dye particles. Usually, a dye is a mixture of two or more colours. The coloured component that is more soluble in water, rises faster and in this way the colours get separated.

This process of separation of components of a mixture is known as chromatography. *Kroma* in Greek means colour. This technique was first used for separation of colours, so this name was given. Chromatography is the technique used for separation of those solutes that dissolve in the same solvent.

With the advancement in technology, newer techniques of chromatography have been developed. You will study about chromatography in higher classes.

Applications

To separate
- colours in a dye
- pigments from natural colours
- drugs from blood.

2.3.6 How can we separate a mixture of two miscible liquids?

Activity 2.8

- Let us try to separate acetone and water from their mixture.
- Take the mixture in a distillation flask. Fit it with a thermometer.
- Arrange the apparatus as shown in Fig. 2.9.
- Heat the mixture slowly keeping a close watch at the thermometer.
- The acetone vaporises, condenses in the condenser and can be collected from the condenser outlet.
- Water is left behind in the distillation flask.

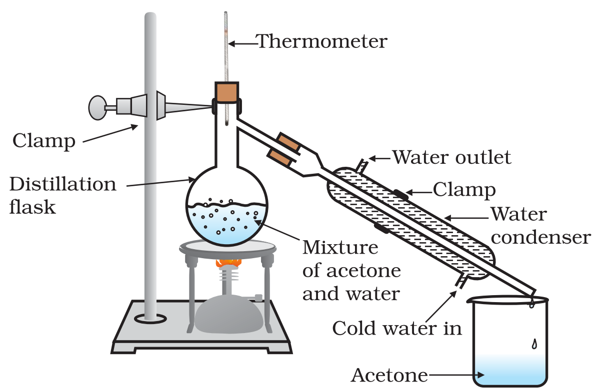


Fig.2.9: *Separation of two miscible liquids by distillation*

Now answer

- *What do you observe as you start heating the mixture?*
- *At what temperature does the thermometer reading become constant for some time?*
- *What is the boiling point of acetone?*
- *Why do the two components separate?*

This method is called distillation. It is used for the separation of components of a mixture containing two miscible liquids that boil without decomposition and have sufficient difference in their boiling points.

To separate a mixture of two or more miscible liquids for which the difference in boiling points is less than 25 K, fractional distillation process is used, for example, for the separation of different gases from air, different factions from petroleum products etc. The apparatus is similar to that for simple distillation, except that a fractionating column is fitted in between the distillation flask and the condenser.

A simple fractionating column is a tube packed with glass beads. The beads provide surface for the vapours to cool and condense repeatedly, as shown in Fig. 2.10.

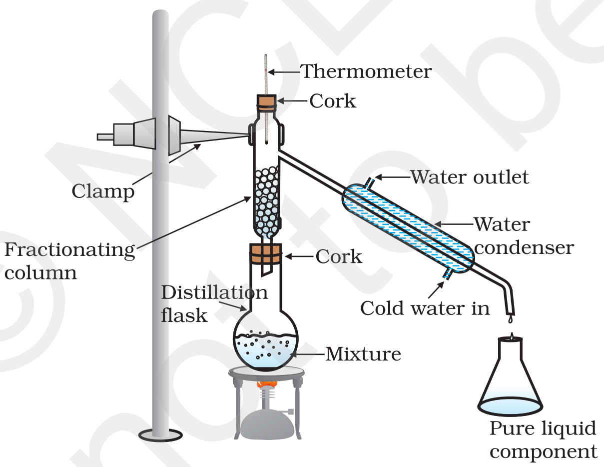
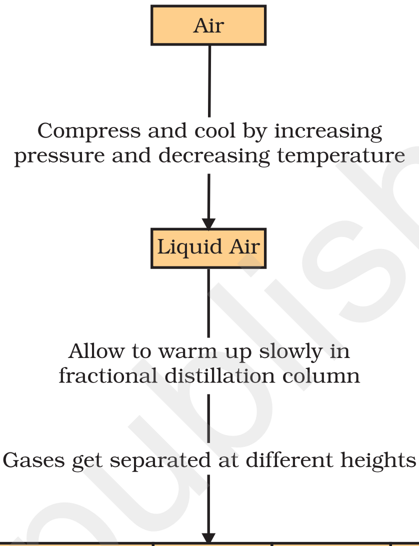


Fig. 2.10: *Fractional distillation*

2.3.7 How can we obtain different gases from air?

Air is a homogeneous mixture and can be separated into its components by fractional distillation. The flow diagram (Fig. 2.11) shows the steps of the process.



	Oxygen	Argon	Nitrogen
Boiling Point (°C)	–183	–186	–196
% Air by Volume	20.9	0.9	78.1

Fig. 2.11: *Flow diagram shows the process of obtaining gases from air*

If we want oxygen gas from air (Fig. 2.12), we have to separate out all the other gases present in the air. The air is compressed by increasing the pressure and is then cooled by decreasing the temperature to get liquid air. This liquid air is allowed to warm-up slowly in a fractional distillation column, where gases get separated at different heights depending upon their boiling points.

Answer the following:

- *Arrange the gases present in air in increasing order of their boiling points.*
- *Which gas forms the liquid first as the air is cooled?*

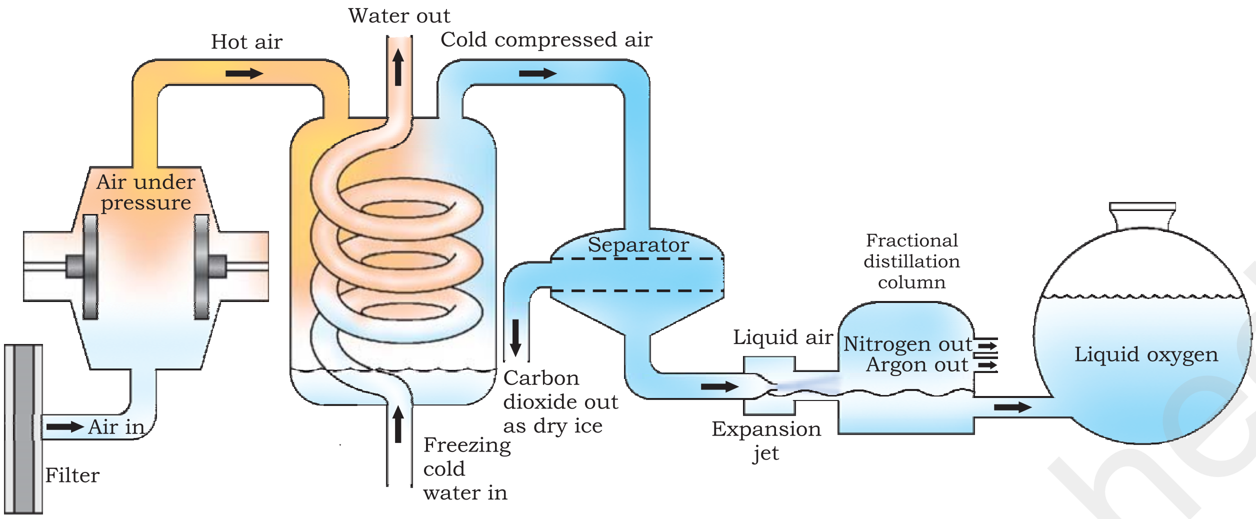


Fig. 2.12: *Separation of components of air*

2.3.8 How can we obtain pure copper sulphate from an impure sample?

Activity 2.9

- Take some (approximately 5 g) impure sample of copper sulphate in a china dish.
- Dissolve it in minimum amount of water.
- Filter the impurities out.
- Evaporate water from the copper sulphate solution so as to get a saturated solution.
- Cover the solution with a filter paper and leave it undisturbed at room temperature to cool slowly for a day.
- You will obtain the crystals of copper sulphate in the china dish.
- This process is called crystallisation.

Now answer

- *What do you observe in the china dish?*
- *Do the crystals look alike?*
- *How will you separate the crystals from the liquid in the china dish?*

The crystallisation method is used to purify solids. For example, the salt we get from sea water can have many impurities in it. To remove these impurities, the process of crystallisation is used. Crystallisation is a process that separates a pure solid in the form of its crystals from a solution. Crystallisation technique is better than simple evaporation technique as –

- some solids decompose or some, like sugar, may get charred on heating to dryness.
- some impurities may remain dissolved in the solution even after filtration. On evaporation these contaminate the solid.

Applications

- Purification of salt that we get from sea water.
- Separation of crystals of alum (*phitkari*) from impure samples.

Thus, by choosing one of the above methods according to the nature of the components of a mixture, we get a pure substance. With advancements in technology many more methods of separation techniques have been devised.

In cities, drinking water is supplied from water works. A flow diagram of a typical water works is shown in Fig. 2.13. From this figure write down the processes involved to get the supply of drinking water to your home from the water works and discuss it in your class.

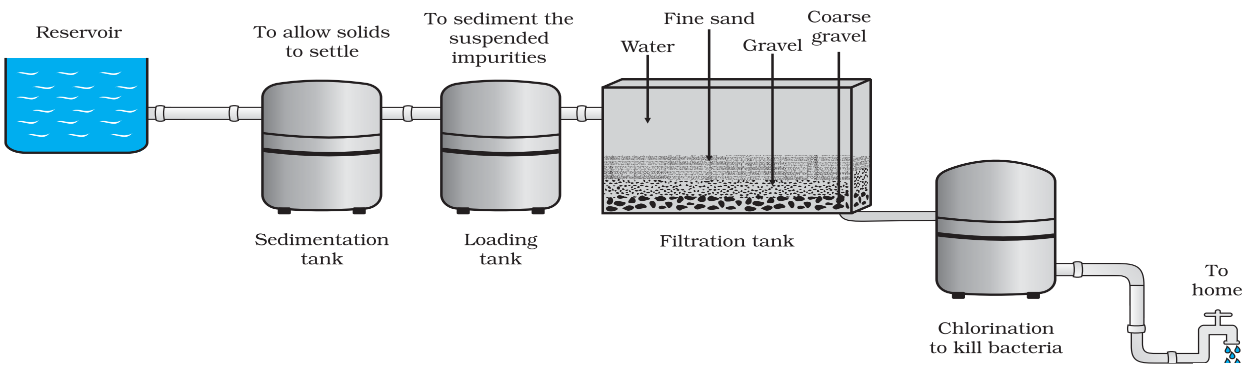


Fig. 2.13: *Water purification system in water works*

Questions

1. *How will you separate a mixture containing kerosene and petrol (difference in their boiling points is more than 25ŢC), which are miscible with each other?*
2. *Name the technique to separate*
   (i) *butter from curd,*
   (ii) *salt from sea-water,*
   (iii) *camphor from salt.*
3. *What type of mixtures are separated by the technique of crystallisation?*

2.4 Physical and Chemical Changes

To understand the difference between a pure substance and a mixture, let us understand the difference between a physical and a chemical change.

In the previous chapter, we have learnt about a few physical properties of matter. The properties that can be observed and specified like colour, hardness, rigidity, fluidity, density, melting point, boiling point etc. are the physical properites.

The interconversion of states is a physical change because these changes occur without a change in composition and no change in the chemical nature of the substance. Although ice, water and water vapour all look different and display different physical properties, they are chemically the same.

Both water and cooking oil are liquid but their chemical characteristics are different. They differ in odour and inflammability. We know that oil burns in air whereas water extinguishes fire. It is this chemical property of oil that makes it different from water. Burning is a chemical change. During this process one substance reacts with another to undergo a change in chemical composition. Chemical change brings change in the chemical properties of matter and we get new substances. A chemical change is also called a chemical reaction.

During burning of a candle, both physical and chemical changes take place. Can you distinguish these?

Questions

1. *Classify the following as chemical or physical changes:*
   - *cutting of trees,*
   - *melting of butter in a pan,*
   - *rusting of almirah,*
   - *boiling of water to form steam,*
   - *passing of electric current, through water and the water breaking down into hydrogen and oxygen gases,*
   - *dissolving common salt in water,*
   - *making a fruit salad with raw fruits, and*
   - *burning of paper and wood.*
2. *Try segregating the things around you as pure substances or mixtures.*

2.5 What are the Types of Pure Substances?

On the basis of their chemical composition, substances can be classified either as elements or compounds.

2.5.1 Elements

Robert Boyle was the first scientist to use the term element in 1661. Antoine Laurent Lavoisier (1743-94), a French chemist, was the first to establish an experimentally useful definition of an element. He defined an element as a basic form of matter that cannot be broken down into simpler substances by chemical reactions.

Elements can be normally divided into metals, non-metals and metalloids.

Metals usually show some or all of the following properties:

- They have a lustre (shine).
- They have silvery-grey or golden-yellow colour.
- They conduct heat and electricity.
- They are ductile (can be drawn into wires).
- They are malleable (can be hammered into thin sheets).
- They are sonorous (make a ringing sound when hit).

Examples of metals are gold, silver, copper, iron, sodium, potassium etc. Mercury is the only metal that is liquid at room temperature.

Non-metals usually show some or all of the following properties:

- They display a variety of colours.
- They are poor conductors of heat and electricity.
- They are not lustrous, sonorous or malleable.

Examples of non-metals are hydrogen, oxygen, iodine, carbon (coal, coke), bromine, chlorine etc. Some elements have intermediate properties between those of metals and non-metals, they are called metalloids; examples are boron, silicon, germanium etc.

More to know

- The number of elements known at present are more than 100. Ninety-two elements are naturally occurring and the rest are man-made.
- Majority of the elements are solid.
- Eleven elements are in gaseous state at room temperature.
- Two elements are liquid at room temperature–mercury and bromine.
- Elements, gallium and cesium become liquid at a temperature slightly above room temperature (303 K).

2.5.2 Compounds

A compound is a substance composed of two or more elements, chemically combined with one another in a fixed proportion.

What do we get when two or more elements are combined?

Activity 2.10

- Divide the class into two groups. Give 5 g of iron filings and 3 g of sulphur powder in a china dish to both the groups.

Group I

- Mix and crush iron filings and sulphur powder.

Group II

- Mix and crush iron filings and sulphur powder. Heat this mixture strongly till red hot. Remove from flame and let the mixture cool.

Groups I and II

- Check for magnetism in the material obtained. Bring a magnet near the material and check if the material is attracted towards the magnet.
- Compare the texture and colour of the material obtained by the groups.
- Add carbon disulphide to one part of the material obtained. Stir well and filter.
- Add dilute sulphuric acid or dilute hydrochloric acid to the other part of

Table 2.2: Mixtures and Compounds

Mixtures	Compounds
1. Elements or compounds just mix together to form a mixture and no new compound is formed.	1. Elements react to form new compounds.
2. A mixture has a variable composition.	2. The composition of each new substance is always fixed.
3, A mixture shows the properties of the constituent substances.	3. The new substance has totally different properties.
4. The constituents can be seperated fairly easily by physical methods.	4. The constituents can be separated only by chemical or electrochemical reactions.

the material obtained. *(Note: teacher supervision is necessary for this activity).*

- Perform all the above steps with both the elements (iron and sulphur) separately.

Now answer

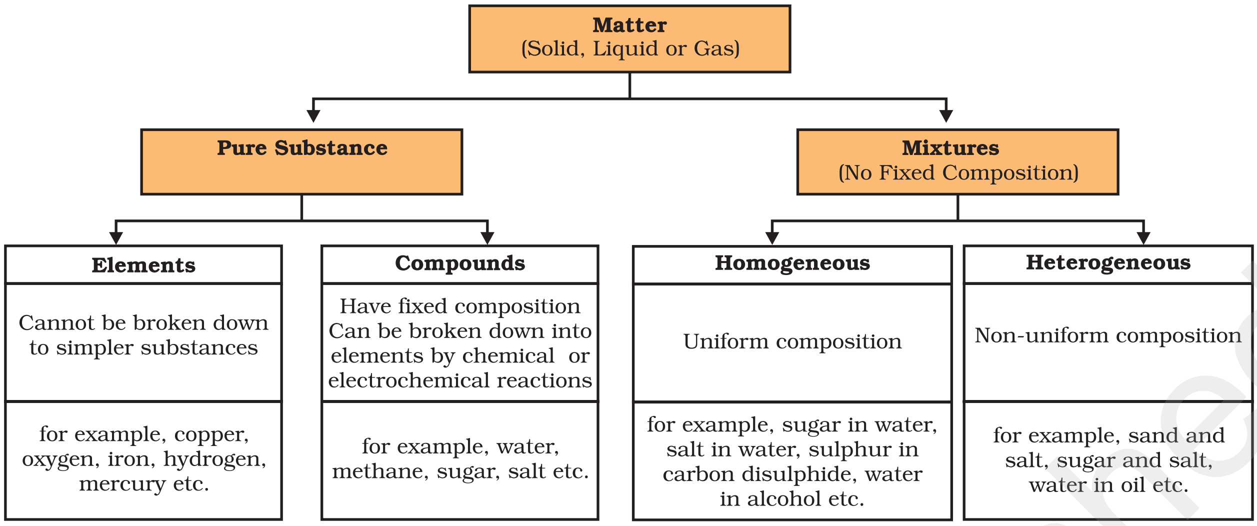
- *Did the material obtained by the two groups look the same?*
- *Which group has obtained a material with magnetic properties?*
- *Can we separate the components of the material obtained?*
- *On adding dilute sulphuric acid or dilute hydrochloric acid, did both the groups obtain a gas? Did the gas in both the cases smell the same or different?*

The gas obtained by Group I is hydrogen, it is colourless, odourless and combustible– it is not advised to do the combustion test for hydrogen in the class. The gas obtained by Group II is hydrogen sulphide. It is a colourless gas with the smell of rotten eggs.

You must have observed that the products obtained by both the groups show different properties, though the starting materials were the same. Group I has carried out the activity involving a physical change whereas in case of Group II, a chemical change (a chemical reaction) has taken place.

- The material obtained by group I is a mixture of the two substances. The substances given are the elements– iron and sulphur.
- The properties of the mixture are the same as that of its constituents.
- The material obtained by group II is a compound.
- On heating the two elements strongly we get a compound, which has totally different properties compared to the combining elements.
- The composition of a compound is the same throughout. We can also observe that the texture and the colour of the compound are the same throughout.

Thus, we can summarise the physical and chemical nature of matter in the following graphical organiser :



What you have learnt

- A mixture contains more than one substance (element and/or compound) mixed in any proportion.
- Mixtures can be separated into pure substances using appropriate separation techniques.
- A solution is a homogeneous mixture of two or more substances. The major component of a solution is called the solvent, and the minor, the solute.
- The concentration of a solution is the amount of solute present per unit volume or per unit mass of the solution/solvent.
- Materials that are insoluble in a solvent and have particles that are visible to naked eyes, form a suspension. A suspension is a heterogeneous mixture.
- Colloids are heterogeneous mixtures in which the particle size is too small to be seen with the naked eye, but is big enough to scatter light. Colloids are useful in industry and daily life. The particles are called the dispersed phase and the medium in which they are distributed is called the dispersion medium.
- Pure substances can be elements or compounds. An element is a form of matter that cannot be broken down by chemical reactions into simpler substances. A compound is a substance composed of two or more different types of elements, chemically combined in a fixed proportion.
- Properties of a compound are different from its constituent elements, whereas a mixture shows the properties of its constituting elements or compounds.

Exercises

1. Which separation techniques will you apply for the separation of the following?
   (a) Sodium chloride from its solution in water.
   (b) Ammonium chloride from a mixture containing sodium chloride and ammonium chloride.
   (c) Small pieces of metal in the engine oil of a car.
   (d) Different pigments from an extract of flower petals.
   (e) Butter from curd.
   (f) Oil from water.
   (g) Tea leaves from tea.
   (h) Iron pins from sand.
   (i) Wheat grains from husk.
   (j) Fine mud particles suspended in water.
2. Write the steps you would use for making tea. Use the words solution, solvent, solute, dissolve, soluble, insoluble, filtrate and residue.
3. Pragya tested the solubility of three different substances at different temperatures and collected the data as given below (results are given in the following table, as grams of substance dissolved in 100 grams of water to form a saturated solution).

Substance Dissolved	**Temperature in K**				
	283	**293**	**313**	**333**	**353**
	Solubility				
Potassium nitrate	21	32	62	106	167
Sodium chloride	36	36	36	37	37
Potassium chloride	35	35	40	46	54
Ammonium chloride	24	37	41	55	66

   (a) What mass of potassium nitrate would be needed to produce a saturated solution of potassium nitrate in 50 grams of water at 313 K?
   (b) Pragya makes a saturated solution of potassium chloride in water at 353 K and leaves the solution to cool at room temperature. What would she observe as the solution cools? Explain.
   (c) Find the solubility of each salt at 293 K. Which salt has the highest solubility at this temperature?
   (d) What is the effect of change of temperature on the solubility of a salt?

4. Explain the following giving examples.
   (a) saturated solution
   (b) pure substance
   (c) colloid
   (d) suspension
5. Classify each of the following as a homogeneous or heterogeneous mixture.
   soda water, wood, air, soil, vinegar, filtered tea.
6. How would you confirm that a colourless liquid given to you is pure water?
7. Which of the following materials fall in the category of a "pure substance"?
   (a) Ice
   (b) Milk
   (c) Iron
   (d) Hydrochloric acid
   (e) Calcium oxide
   (f) Mercury
   (g) Brick
   (h) Wood
   (i) Air.
8. Identify the solutions among the following mixtures.
   (a) Soil
   (b) Sea water
   (c) Air
   (d) Coal
   (e) Soda water.
9. Which of the following will show "Tyndall effect"?
   (a) Salt solution
   (b) Milk
   (c) Copper sulphate solution
   (d) Starch solution.
10. Classify the following into elements, compounds and mixtures.
   (a) Sodium
   (b) Soil
   (c) Sugar solution
   (d) Silver
   (e) Calcium carbonate
   (f) Tin
   (g) Silicon

(h) Coal
(i) Air
(j) Soap
(k) Methane
(l) Carbon dioxide
(m) Blood

11. Which of the following are chemical changes?
    (a) Growth of a plant
    (b) Rusting of iron
    (c) Mixing of iron filings and sand
    (d) Cooking of food
    (e) Digestion of food
    (f) Freezing of water
    (g) Burning of a candle.

Group Activity

Take an earthen pot (*mutka*), some pebbles and sand. Design a small-scale filtration plant that you could use to clean muddy water.

Chapter 3

Atoms and Molecules

Ancient Indian and Greek philosophers have always wondered about the unknown and unseen form of matter. The idea of divisibility of matter was considered long back in India, around 500 BC. An Indian philosopher Maharishi Kanad, postulated that if we go on dividing matter (*padarth*), we shall get smaller and smaller particles. Ultimately, a time will come when we shall come across the smallest particles beyond which further division will not be possible. He named these particles *Parmanu*. Another Indian philosopher, Pakudha Katyayama, elaborated this doctrine and said that these particles normally exist in a combined form which gives us various forms of matter.

Around the same era, ancient Greek philosophers – Democritus and Leucippus suggested that if we go on dividing matter, a stage will come when particles obtained cannot be divided further. Democritus called these indivisible particles atoms (meaning indivisible). All this was based on philosophical considerations and not much experimental work to validate these ideas could be done till the eighteenth century.

By the end of the eighteenth century, scientists recognised the difference between elements and compounds and naturally became interested in finding out how and why elements combine and what happens when they combine.

Antoine L. Lavoisier laid the foundation of chemical sciences by establishing two important laws of chemical combination.

3.1 Laws of Chemical Combination

The following two laws of chemical combination were established after much experimentations by Lavoisier and Joseph L. Proust.

3.1.1 Law of conservation of mass

Is there a change in mass when a chemical change (chemical reaction) takes place?

Activity 3.1

- Take one of the following sets, X and Y of chemicals–

	X	***Y***
(i)	copper sulphate	sodium carbonate
(ii)	barium chloride	sodium sulphate
(iii)	lead nitrate	sodium chloride

- Prepare separately a 5% solution of any one pair of substances listed under X and Y in water.
- Take a little amount of solution of Y in a conical flask and some solution of X in an ignition tube.
- Hang the ignition tube in the flask carefully; see that the solutions do not get mixed. Put a cork on the flask (see Fig. 3.1).

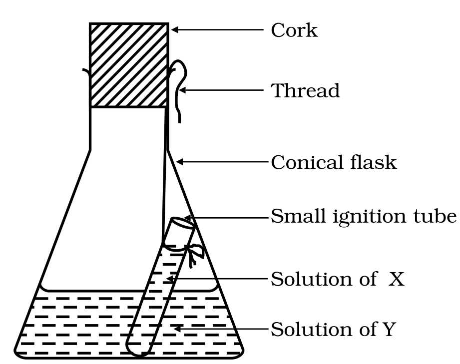


Fig. 3.1: *Ignition tube containing solution of X, dipped in a conical flask containing solution of Y.*

- Weigh the flask with its contents carefully.
- Now tilt and swirl the flask, so that the solutions X and Y get mixed.
- Weigh again.
- What happens in the reaction flask?
- Do you think that a chemical reaction has taken place?
- Why should we put a cork on the mouth of the flask?
- Does the mass of the flask and its contents change?

Law of conservation of mass states that mass can neither be created nor destroyed in a chemical reaction.

3.1.2 LAW OF CONSTANT PROPORTIONS

Lavoisier, along with other scientists, noted that many compounds were composed of two or more elements and each such compound had the same elements in the same proportions, irrespective of where the compound came from or who prepared it.

In a compound such as water, the ratio of the mass of hydrogen to the mass of oxygen is always 1:8, whatever the source of water. Thus, if 9 g of water is decomposed, 1 g of hydrogen and 8 g of oxygen are always obtained. Similarly in ammonia, nitrogen and hydrogen are always present in the ratio 14:3 by mass, whatever the method or the source from which it is obtained.

This led to the law of constant proportions which is also known as the law of definite proportions. This law was stated by Proust as "*In a chemical substance the elements are always present in definite proportions by mass*".

The next problem faced by scientists was to give appropriate explanations of these laws. British chemist John Dalton provided the basic theory about the nature of matter. Dalton picked up the idea of divisibility of matter, which was till then just a philosophy. He took the name 'atoms' as given by the Greeks and said that the smallest particles of matter are atoms. His theory was based on the laws of chemical combination. Dalton's atomic theory provided an explanation for the law of conservation of mass and the law of definite proportions.

John Dalton

John Dalton was born in a poor weaver's family in 1766 in England. He began his career as a teacher at the age of twelve. Seven years later he became a school principal. In 1793, Dalton left for Manchester to teach mathematics, physics and chemistry in a college. He spent most of his life there teaching and researching. In 1808, he presented his atomic theory which was a turning point in the study of matter.

According to Dalton's atomic theory, all matter, whether an element, a compound or a mixture is composed of small particles called atoms. The postulates of this theory may be stated as follows:

(i) All matter is made of very tiny particles called atoms.
(ii) Atoms are indivisible particles, which cannot be created or destroyed in a chemical reaction.
(iii) Atoms of a given element are identical in mass and chemical properties.
(iv) Atoms of different elements have different masses and chemical properties.
(v) Atoms combine in the ratio of small whole numbers to form compounds.
(vi) The relative number and kinds of atoms are constant in a given compound.

You will study in the next chapter that all atoms are made up of still smaller particles.

Questions

1. *In a reaction, 5.3 g of sodium carbonate reacted with 6 g of ethanoic acid. The products were 2.2 g of carbon dioxide, 0.9 g water and 8.2 g of sodium ethanoate. Show that these*

observations are in agreement with the law of conservation of mass.
sodium carbonate + ethanoic acid → sodium ethanoate + carbon dioxide + water

2. *Hydrogen and oxygen combine in the ratio of 1:8 by mass to form water. What mass of oxygen gas would be required to react completely with 3 g of hydrogen gas?*
3. *Which postulate of Dalton's atomic theory is the result of the law of conservation of mass?*
4. *Which postulate of Dalton's atomic theory can explain the law of definite proportions?*

3.2 What is an Atom?

Have you ever observed a mason building walls, from these walls a room and then a collection of rooms to form a building? What is the building block of the huge building? What about the building block of an ant-hill? It is a small grain of sand. Similarly, the building blocks of all matter are atoms.

How big are atoms?

Atoms are very small, they are smaller than anything that we can imagine or compare with. More than millions of atoms when stacked would make a layer barely as thick as this sheet of paper.

Atomic radius is measured in nanometres.

$1/10^9 \text{ m} = 1 \text{ nm}$

$1 \text{ m} = 10^9 \text{ nm}$

Relative Sizes	
Radii (in m)	**Example**
10^{-10}	Atom of hydrogen
10^{-9}	Molecule of water
10^{-8}	Molecule of haemoglobin
10^{-4}	Grain of sand
10^{-2}	Ant
10^{-1}	Watermelon

We might think that if atoms are so insignificant in size, why should we care about them? This is because our entire world is made up of atoms. We may not be able to see them, but they are there, and constantly affecting whatever we do. Through modern techniques, we can now produce magnified images of surfaces of elements showing atoms.

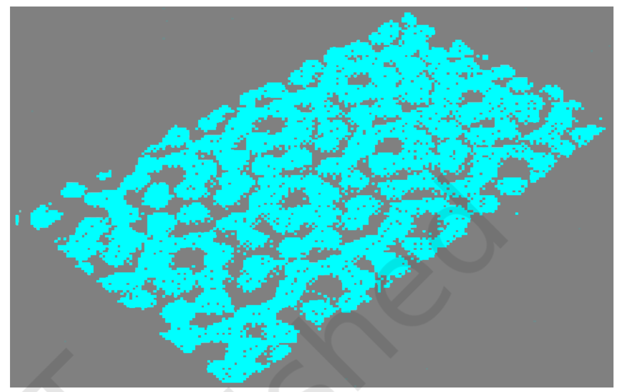


Fig. 3.2: *An image of the surface of silicon*

3.2.1 What are the modern day symbols of atoms of different elements?

Dalton was the first scientist to use the symbols for elements in a very specific sense. When he used a symbol for an element he also meant a definite quantity of that element, that is, one atom of that element. Berzilius suggested that the symbols of elements be made from one or two letters of the name of the element.

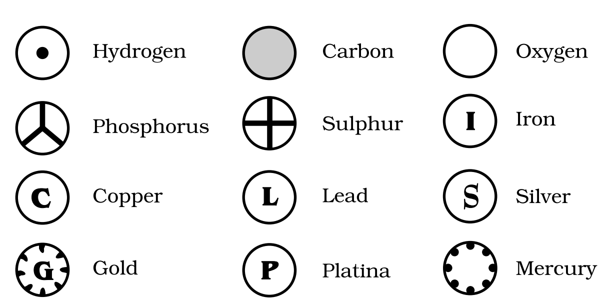


Fig. 3.3: *Symbols for some elements as proposed by Dalton*

In the beginning, the names of elements were derived from the name of the place where they were found for the first time. For example, the name copper was taken from Cyprus. Some names were taken from specific colours. For example, gold was taken from the English word meaning yellow. Now-a-days, IUPAC (International Union of Pure and Applied Chemistry) approves names of elements. Many of the symbols are the first one or two letters of the element's name in English. The first letter of a symbol is always written as a capital letter (uppercase) and the second letter as a small letter (lowercase).

For example

(i) hydrogen, H
(ii) aluminium, Al and not AL
(iii) cobalt, Co and not CO.

Symbols of some elements are formed from the first letter of the name and a letter, appearing later in the name. Examples are: (i) chlorine, Cl, (ii) zinc, Zn etc.

Other symbols have been taken from the names of elements in Latin, German or Greek. For example, the symbol of iron is Fe from its Latin name ferrum, sodium is Na from natrium, potassium is K from kalium. Therefore, each element has a name and a unique chemical symbol.

Table 3.1: Symbols for some elements

Element	Symbol	Element	Symbol	Element	Symbol
Aluminium	Al	Copper	Cu	Nitrogen	N
Argon	Ar	Fluorine	F	Oxygen	O
Barium	Ba	Gold	Au	Potassium	K
Boron	B	Hydrogen	H	Silicon	Si
Bromine	Br	Iodine	I	Silver	Ag
Calcium	Ca	Iron	Fe	Sodium	Na
Carbon	C	Lead	Pb	Sulphur	S
Chlorine	Cl	Magnesium	Mg	Uranium	U
Cobalt	Co	Neon	Ne	Zinc	Zn

(The above table is given for you to refer to whenever you study about elements. Do not bother to memorise all in one go. With the passage of time and repeated usage you will automatically be able to reproduce the symbols).

3.2.2 Atomic mass

The most remarkable concept that Dalton's atomic theory proposed was that of the atomic mass. According to him, each element had a characteristic atomic mass. The theory could explain the law of constant proportions so well that scientists were prompted to measure the atomic mass of an atom. Since determining the mass of an individual atom was a relatively difficult task, relative atomic masses were determined using the laws of chemical combinations and the compounds formed.

Let us take the example of a compound, carbon monoxide (CO) formed by carbon and oxygen. It was observed experimentally that 3 g of carbon combines with 4 g of oxygen to form CO. In other words, carbon combines with 4/3 times its mass of oxygen. Suppose we define the atomic mass unit (earlier abbreviated as 'amu', but according to the latest IUPAC recommendations, it is now written as 'u' – unified mass) as equal to the mass of one carbon atom, then we would assign carbon an atomic mass of 1.0 u and oxygen an atomic mass of 1.33 u. However, it is more convenient to have these numbers as whole numbers or as near to a whole numbers as possible. While searching for various atomic mass units, scientists initially took 1/16 of the mass of an atom of naturally occurring oxygen as the unit. This was considered relevant due to two reasons:

- oxygen reacted with a large number of elements and formed compounds.
- this atomic mass unit gave masses of most of the elements as whole numbers.

However, in 1961 for a universally accepted atomic mass unit, carbon-12 isotope was chosen as the standard reference for measuring atomic masses. One atomic mass unit is a mass unit equal to exactly one-twelfth ($1/12^{th}$) the mass of one atom of carbon-12. The relative atomic masses of all elements have been found with respect to an atom of carbon-12.

Imagine a fruit seller selling fruits without any standard weight with him. He takes a watermelon and says, “this has a mass equal to 12 units” (12 watermelon units or 12 fruit mass units). He makes twelve equal pieces of the watermelon and finds the mass of each fruit he is selling, relative to the mass of one piece of the watermelon. Now he sells his fruits by relative fruit mass unit (fmu), as in Fig. 3.4.

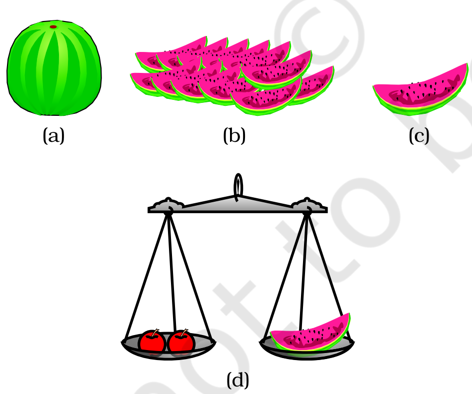


Fig. 3.4 : *(a) Watermelon, (b) 12 pieces, (c) 1/12 of watermelon, (d) how the fruit seller can weigh the fruits using pieces of watermelon*

Similarly, the relative atomic mass of the atom of an element is defined as the average mass of the atom, as compared to $1/12^{th}$ the mass of one carbon-12 atom.

Table 3.2: Atomic masses of a few elements

Element	Atomic Mass (u)
Hydrogen	1
Carbon	12
Nitrogen	14
Oxygen	16
Sodium	23
Magnesium	24
Sulphur	32
Chlorine	35.5
Calcium	40

3.2.3 How do atoms exist?

Atoms of most elements are not able to exist independently. Atoms form molecules and ions. These molecules or ions aggregate in large numbers to form the matter that we can see, feel or touch.

Questions

1. *Define the atomic mass unit.*
2. *Why is it not possible to see an atom with naked eyes?*

3.3 What is a Molecule?

A molecule is in general a group of two or more atoms that are chemically bonded together, that is, tightly held together by attractive forces. A molecule can be defined as the smallest particle of an element or a compound that is capable of an independent existence and shows all the properties of that substance. Atoms of the same element or of different elements can join together to form molecules.

3.3.1 Molecules of elements

The molecules of an element are constituted by the same type of atoms. Molecules of many elements, such as argon (Ar), helium (He) etc. are made up of only one atom of that element. But this is not the case with most of the non-metals. For example, a molecule of oxygen consists of two atoms of oxygen and hence it is known as a diatomic molecule, O_2. If 3 atoms of oxygen unite into a molecule, instead of the usual 2, we get ozone. The number of atoms constituting a molecule is known as its atomicity.

Metals and some other elements, such as carbon, do not have a simple structure but consist of a very large and indefinite number of atoms bonded together.

Let us look at the atomicity of some non-metals.

Table 3.3 : Atomicity of some elements

Type of Element	Name	Atomicity
Non-Metal	Argon	Monoatomic
	Helium	Monoatomic
	Oxygen	Diatomic
	Hydrogen	Diatomic
	Nitrogen	Diatomic
	Chlorine	Diatomic
	Phosphorus	Tetra-atomic
	Sulphur	Poly-atomic

3.3.2 Molecules of compounds

Atoms of different elements join together in definite proportions to form molecules of compounds. Few examples are given in Table 3.4.

Table 3.4 : Molecules of some compounds

Compound	Combining Elements	Ratio by Mass
Water	Hydrogen, Oxygen	1:8
Ammonia	Nitrogen, Hydrogen	14:3
Carbon dioxide	Carbon, Oxygen	3:8

Activity 3.2

- Refer to Table 3.4 for ratio by mass of atoms present in molecules and Table 3.2 for atomic masses of elements. Find the ratio by number of the atoms of elements in the molecules of compounds given in Table 3.4.
- The ratio by number of atoms for a water molecule can be found as follows:

Element	Ratio by mass	Atomic mass (u)	Mass ratio/ atomic mass	Simplest ratio
H	*1*	*1*	$\frac{1}{1}=1$	*2*
O	*8*	*16*	$\frac{8}{16}=\frac{1}{2}$	*1*

- Thus, the ratio by number of atoms for water is H:O = 2:1.

3.3.3 What is an ion?

Compounds composed of metals and non-metals contain charged species. The charged species are known as *ions*. An ion is a charged particle and can be negatively or positively charged. A negatively charged ion is called an 'anion' and the positively charged ion, a 'cation'. Take, for example, sodium chloride (NaCl). Its constituent particles are positively charged sodium ions (Na^+) and negatively charged chloride ions (Cl^-). Ions may consist of a single charged atom or a group of atoms that have a net charge on them. A group of atoms carrying a charge is known as a polyatomic ion (Table 3.6). We shall learn more about the formation of ions in Chapter 4.

Table 3.5: Some ionic compounds

Ionic Compound	Constituting Elements	Ratio by Mass
Calcium oxide	Calcium and oxygen	5:2
Magnesium sulphide	Magnesium and sulphur	3:4
Sodium chloride	Sodium and chlorine	23:35.5

3.4 Writing Chemical Formulae

The chemical formula of a compound is a symbolic representation of its composition. The chemical formulae of different compounds can be written easily. For this exercise, we need to learn the symbols and combining capacity of the elements.

The combining power (or capacity) of an element is known as its valency. Valency can be used to find out how the atoms of an element will combine with the atom(s) of another element to form a chemical compound. The valency of the atom of an element can be thought of as hands or arms of that atom.

Human beings have two arms and an octopus has eight. If one octopus has to catch hold of a few people in such a manner that all the eight arms of the octopus and both arms of all the humans are locked, how many humans do you think the octopus can hold? Represent the octopus with O and humans with H. Can you write a formula for this combination? Do you get OH_4 as the formula? The subscript 4 indicates the number of humans held by the octopus.

The valencies of some common ions are given in Table 3.6. We will learn more about valency in the next chapter.

Table 3.6: Names and symbols of some ions

Valency	Name of ion	Symbol	Non-metallic element	Symbol	Polyatomic ions	Symbol
1.	Sodium	Na^+	Hydrogen	H^+	Ammonium	NH_4^+
	Potassium	K^+	Hydride	H^-	Hydroxide	OH^-
	Silver	Ag^+	Chloride	Cl^-	Nitrate	NO_3^-
	Copper (I)*	Cu^+	Bromide	Br^-	Hydrogen carbonate	HCO_3^-
			Iodide	I^-		
2.	Magnesium	Mg^{2+}	Oxide	O^{2-}	Carbonate	CO_3^{2-}
	Calcium	Ca^{2+}	Sulphide	S^{2-}	Sulphite	SO_3^{2-}
	Zinc	Zn^{2+}			Sulphate	SO_4^{2-}
	Iron (II)*	Fe^{2+}				
	Copper (II)*	Cu^{2+}				
3.	Aluminium	Al^{3+}	Nitride	N^{3-}	Phosphate	PO_4^{3-}
	Iron (III)*	Fe^{3+}				

* *Some elements show more than one valency. A Roman numeral shows their valency in a bracket.*

The rules that you have to follow while writing a chemical formula are as follows:

- the valencies or charges on the ion must balance.
- when a compound consists of a metal and a non-metal, the name or symbol of the metal is written first. For example: calcium oxide (CaO), sodium chloride (NaCl), iron sulphide (FeS), copper oxide (CuO) etc., where oxygen, chlorine, sulphur are non-metals and are written on the right, whereas calcium, sodium, iron and copper are metals, and are written on the left.
- in compounds formed with polyatomic ions, the ion is enclosed in a bracket before writing the number to indicate the ratio. In case the number of polyatomic ion is one, the bracket is not required. For example, NaOH.

3.4.1 Formulae of simple compounds

The simplest compounds, which are made up of two different elements are called binary compounds. Valencies of some ions are given in Table 3.6. You can use these to write formulae for compounds.

While writing the chemical formulae for compounds, we write the constituent elements and their valencies as shown below. Then we must crossover the valencies of the combining atoms.

Examples

1. Formula of hydrogen chloride

Symbol H Cl

Valency 1 1

Formula of the compound would be HCl.

2. Formula of hydrogen sulphide

Symbol H S

Valency 1 2

Formula : H_2S

3. Formula of carbon tetrachloride

Symbol C Cl

Valency 4 1

Formula : CCl_4

For magnesium chloride, we write the symbol of cation (Mg^{2+}) first followed by the symbol of anion (Cl^-). Then their charges are criss-crossed to get the formula.

4. Formula of magnesium chloride

Symbol Mg Cl

Charge 2+ 1-

Formula : $MgCl_2$

Thus, in magnesium chloride, there are two chloride ions (Cl^-) for each magnesium ion (Mg^{2+}). The positive and negative charges must balance each other and the overall structure must be neutral. Note that in the formula, the charges on the ions are not indicated.

Some more examples

(a) Formula for aluminium oxide:

Symbol Al O

Charge 3+ 2-

Formula : Al_2O_3

(b) Formula for calcium oxide:

Symbol Ca O

Charge 2+ 2-

Here, the valencies of the two elements are the same. You may arrive at the formula Ca_2O_2. But we simplify the formula as CaO.

(c) Formula of sodium nitrate:

Symbol/ Formula	Na	NO_3
Charge	1+	1-

Formula : $NaNO_3$

(d) Formula of calcium hydroxide:

Symbol/ Formula	Ca	OH
Charge	2+	1-

Formula : $Ca(OH)_2$

Note that the formula of calcium hydroxide is $Ca(OH)_2$ and not $CaOH_2$. We use brackets when we have two or more of the same ions in the formula. Here, the bracket around OH with a subscript 2 indicates that there are two hydroxyl (OH) groups joined to one calcium atom. In other words, there are two atoms each of oxygen and hydrogen in calcium hydroxide.

(e) Formula of sodium carbonate:

Symbol/ Formula	Na	CO_3
Charge	1+	2-

Formula : Na_2CO_3

In the above example, brackets are not needed if there is only one ion present.

(f) Formula of ammonium sulphate:

Formula	NH_4	SO_4
Charge	1+	2-

Formula : $(NH_4)_2SO_4$

Questions

1. *Write down the formulae of*
   - *(i) sodium oxide*
   - *(ii) aluminium chloride*
   - *(iii) sodium suphide*
   - *(iv) magnesium hydroxide*
2. *Write down the names of compounds represented by the following formulae:*
   - *(i) $Al_2(SO_4)_3$*
   - *(ii) $CaCl_2$*
   - *(iii) K_2SO_4*
   - *(iv) KNO_3*
   - *(v) $CaCO_3$.*
3. *What is meant by the term chemical formula?*
4. *How many atoms are present in a*
   - *(i) H_2S molecule and*
   - *(ii) PO_4^{3-} ion?*

3.5 Molecular Mass and Mole Concept

3.5.1 Molecular mass

In section 3.2.2 we discussed the concept of atomic mass. This concept can be extended to calculate molecular masses. The molecular mass of a substance is the sum of the atomic masses of all the atoms in a molecule of the substance. It is therefore the relative mass of a molecule expressed in *atomic mass units (u).*

Example 3.1 (a) Calculate the relative molecular mass of water (H_2O). (b) Calculate the molecular mass of HNO_3.

Solution:

(a) Atomic mass of hydrogen = 1u, oxygen = 16 u

So the molecular mass of water, which contains two atoms of hydrogen and one atom of oxygen is $= 2 \times 1 + 1 \times 16$ $= 18$ u

(b) The molecular mass of HNO_3 = the atomic mass of H + the atomic mass of N+ 3 × the atomic mass of O

= 1 + 14 + 48 = 63 u

3.5.2 Formula unit mass

The formula unit mass of a substance is a sum of the atomic masses of all atoms in a formula unit of a compound. Formula unit mass is calculated in the same manner as we calculate the molecular mass. The only difference is that we use the word formula unit for those substances whose constituent particles are ions. For example, sodium chloride as discussed above, has a formula unit NaCl. Its formula unit mass can be calculated as–

$$1 \times 23 + 1 \times 35.5 = 58.5 \text{ u}$$

Example 3.2 Calculate the formula unit mass of $CaCl_2$.

Solution:

Atomic mass of Ca
+ (2 × atomic mass of Cl)
= 40 + 2 × 35.5 = 40 + 71 = 111 u

Questions

1. *Calculate the molecular masses of H_2, O_2, Cl_2, CO_2, CH_4, C_2H_6, C_2H_4, NH_3, CH_3OH.*
2. *Calculate the formula unit masses of ZnO, Na_2O, K_2CO_3, given atomic masses of Zn = 65 u, Na = 23 u, K = 39 u, C = 12 u, and O = 16 u.*

3.5.3 Mole concept

Take an example of the reaction of hydrogen and oxygen to form water:

$$2H_2 + O_2 \rightarrow 2H_2O.$$

The above reaction indicates that

(i) two molecules of hydrogen combine with one molecule of oxygen to form two molecules of water, or

(ii) 4 u of hydrogen molecules combine with 32 u of oxygen molecules to form 36 u of water molecules.

We can infer from the above equation that the quantity of a substance can be characterised by its mass or the number of molecules. But, a chemical reaction equation indicates directly the number of atoms or molecules taking part in the reaction. Therefore, it is more convenient to refer to the quantity of a substance in terms of the number of its molecules or atoms, rather than their masses. So, a new unit "mole" was introduced. One mole of any species (atoms,

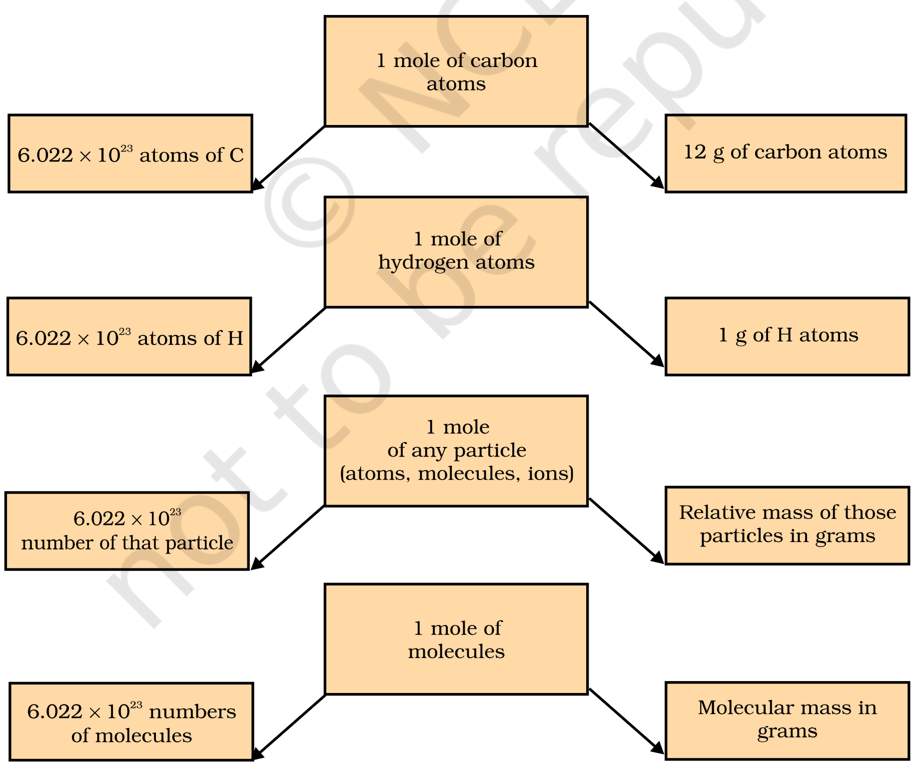


Fig. 3.5: *Relationship between mole, Avogadro number and mass*

molecules, ions or particles) is that quantity in number having a mass equal to its atomic or molecular mass in grams.

The number of particles (atoms, molecules or ions) present in 1 mole of any substance is fixed, with a value of 6.022×10^{23}. This is an experimentally obtained value. This number is called the Avogadro Constant or Avogadro Number *(represented by* N_0), named in honour of the Italian scientist, Amedeo Avogadro.

1 mole (of anything) = 6.022×10^{23} in number,
as, 1 dozen = 12 nos.
1 gross = 144 nos.

Besides being related to a number, a mole has one more advantage over a dozen or a gross. This advantage is that mass of 1 mole of a particular substance is also fixed.

The mass of 1 mole of a substance is equal to its relative atomic or molecular mass in grams. The atomic mass of an element gives us the mass of one atom of that element in atomic mass units (u). To get the mass of 1 mole of atom of that element, that is, molar mass, we have to take the same numerical value but change the units from 'u' to 'g'. Molar mass of atoms is also known as gram atomic mass. For example, atomic mass of hydrogen=1u. So, gram atomic mass of hydrogen = 1 g.

1 u hydrogen has only 1 atom of hydrogen
1 g hydrogen has 1 mole atoms, that is, 6.022×10^{23} atoms of hydrogen.
Similarly,
16 u oxygen has only 1 atom of oxygen,
16 g oxygen has 1 mole atoms, that is, 6.022×10^{23} atoms of oxygen.

To find the gram molecular mass or molar mass of a molecule, we keep the numerical value the same as the molecular mass, but simply change units as above from u to g. For example, as we have already calculated, molecular mass of water (H_2O) is 18 u. From here we understand that

18 u water has only 1 molecule of water,
18 g water has 1 mole molecules of water, that is, 6.022×10^{23} molecules of water.

Chemists need the number of atoms and molecules while carrying out reactions, and for this they need to relate the mass in grams to the number. It is done as follows:

1 mole = 6.022×10^{23} number
= Relative mass in grams.

Thus, a mole is the chemist's counting unit.

The word "mole" was introduced around 1896 by Wilhelm Ostwald who derived the term from the Latin word *moles* meaning a 'heap' or 'pile'. A substance may be considered as a heap of atoms or molecules. The unit mole was accepted in 1967 to provide a simple way of reporting a large number– the massive heap of atoms and molecules in a sample.

Example 3.3

1. Calculate the number of moles for the following:
   (i) 52 g of He (finding mole from mass)
   (ii) 12.044×10^{23} number of He atoms (finding mole from number of particles).

Solutions:

No. of moles	=	n
Given mass	=	m
Molar mass	=	M
Given number of particles	=	N
Avogadro number of particles	=	N_0

(i) Atomic mass of He = 4 u
Molar mass of He = 4g

Thus, the number of moles

$$= \frac{\text{given mass}}{\text{molar mass}}$$

$$\Rightarrow n = \frac{m}{M} = \frac{52}{4} = 13$$

(ii) we know,
1 mole = 6.022×10^{23}
The number of moles

$$= \frac{\text{given number of particles}}{\text{Avogadro number}}$$

$$\Rightarrow n = \frac{N}{N_0} = \frac{12.044 \times 10^{23}}{6.022 \times 10^{23}} = 2$$

Example 3.4 Calculate the mass of the following:

(i) 0.5 mole of N_2 gas (mass from mole of molecule)

(ii) 0.5 mole of N atoms (mass from mole of atom)

(iii) 3.011×10^{23} number of N atoms (mass from number)

(iv) 6.022×10^{23} number of N_2 molecules (mass from number)

Solutions:

(i) mass = molar mass × number of moles

$$\Rightarrow m = M \times n = 28 \times 0.5 = 14\,g$$

(ii) mass = molar mass × number of moles

$$\Rightarrow m = M \times n = 14 \times 0.5 = 7\,g$$

(iii) The number of moles, n

$$= \frac{\text{given number of particles}}{\text{Avogadro number}} = \frac{N}{N_0}$$

$$= \frac{3.011 \times 10^{23}}{6.022 \times 10^{23}}$$

$$\Rightarrow m = M \times n = 14 \times \frac{3.011 \times 10^{23}}{6.022 \times 10^{23}}$$

$$= 14 \times 0.5 = 7\,g$$

(iv) $n = \frac{N}{N_0}$

$$\Rightarrow m = M \times \frac{N}{N_0} = 28 \times \frac{6.022 \times 10^{23}}{6.022 \times 10^{23}}$$

$$= 28 \times 1 = 28\,g$$

Example 3.5 Calculate the number of particles in each of the following:

(i) 46 g of Na atoms (number from mass)

(ii) 8 g O_2 molecules (number of molecules from mass)

(iii) 0.1 mole of carbon atoms (number from given moles)

Solutions:

(i) The number of atoms

$$= \frac{\text{given mass}}{\text{molar mass}} \times \text{Avogadro number}$$

$$\Rightarrow N = \frac{m}{M} \times N_0$$

$$\Rightarrow N = \frac{46}{23} \times 6.022 \times 10^{23}$$

$$\Rightarrow N = 12.044 \times 10^{23}$$

(ii) The number of molecules

$$= \frac{\text{given mass}}{\text{molar mass}} \times \text{Avogadro number}$$

$$\Rightarrow N = \frac{m}{M} \times N_0$$

atomic mass of oxygen = 16 u

∴ molar mass of O_2 molecules = 16 × 2 = 32g

$$\Rightarrow N = \frac{8}{32} \times 6.022 \times 10^{23}$$

$$\Rightarrow N = 1.5055 \times 10^{23}$$

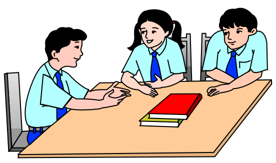
$$\simeq 1.51 \times 10^{23}$$

(iii) The number of particles (atom) = number of moles of particles × Avogadro number

$N = n \times N_0 = 0.1 \times 6.022 \times 10^{23}$
$= 6.022 \times 10^{22}$

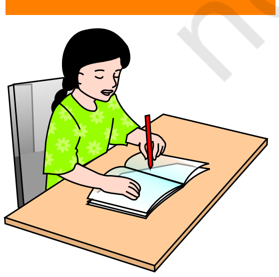
Questions

1. *If one mole of carbon atoms weighs 12 grams, what is the mass (in grams) of 1 atom of carbon?*
2. *Which has more number of atoms, 100 grams of sodium or 100 grams of iron (given, atomic mass of Na = 23 u, Fe = 56 u)?*



What you have learnt

- During a chemical reaction, the sum of the masses of the reactants and products remains unchanged. This is known as the Law of Conservation of Mass.
- In a pure chemical compound, elements are always present in a definite proportion by mass. This is known as the Law of Definite Proportions.
- An atom is the smallest particle of the element that cannot usually exist independently and retain all its chemical properties.
- A molecule is the smallest particle of an element or a compound capable of independent existence under ordinary conditions. It shows all the properties of the substance.
- A chemical formula of a compound shows its constituent elements and the number of atoms of each combining element.
- Clusters of atoms that act as an ion are called polyatomic ions. They carry a fixed charge on them.
- The chemical formula of a molecular compound is determined by the valency of each element.
- In ionic compounds, the charge on each ion is used to determine the chemical formula of the compound.
- Scientists use the relative atomic mass scale to compare the masses of different atoms of elements. Atoms of carbon-12 isotopes are assigned a relative atomic mass of 12 and the relative masses of all other atoms are obtained by comparison with the mass of a carbon-12 atom.
- The Avogadro constant 6.022×10^{23} is defined as the number of atoms in exactly 12 g of carbon-12.
- The mole is the amount of substance that contains the same number of particles (atoms/ ions/ molecules/ formula units etc.) as there are atoms in exactly 12 g of carbon-12.
- Mass of 1 mole of a substance is called its molar mass.



Exercises

1. A 0.24 g sample of compound of oxygen and boron was found by analysis to contain 0.096 g of boron and 0.144 g of oxygen. Calculate the percentage composition of the compound by weight.
2. When 3.0 g of carbon is burnt in 8.00 g oxygen, 11.00 g of carbon dioxide is produced. What mass of carbon dioxide will

be formed when 3.00 g of carbon is burnt in 50.00 g of oxygen? Which law of chemical combination will govern your answer?

3. What are polyatomic ions? Give examples.
4. Write the chemical formulae of the following.
   (a) Magnesium chloride
   (b) Calcium oxide
   (c) Copper nitrate
   (d) Aluminium chloride
   (e) Calcium carbonate.
5. Give the names of the elements present in the following compounds.
   (a) Quick lime
   (b) Hydrogen bromide
   (c) Baking powder
   (d) Potassium sulphate.
6. Calculate the molar mass of the following substances.
   (a) Ethyne, C_2H_2
   (b) Sulphur molecule, S_8
   (c) Phosphorus molecule, P_4 (Atomic mass of phosphorus = 31)
   (d) Hydrochloric acid, HCl
   (e) Nitric acid, HNO_3
7. What is the mass of—
   (a) 1 mole of nitrogen atoms?
   (b) 4 moles of aluminium atoms (Atomic mass of aluminium = 27)?
   (c) 10 moles of sodium sulphite (Na_2SO_3)?
8. Convert into mole.
   (a) 12 g of oxygen gas
   (b) 20 g of water
   (c) 22 g of carbon dioxide.
9. What is the mass of:
   (a) 0.2 mole of oxygen atoms?
   (b) 0.5 mole of water molecules?
10. Calculate the number of molecules of sulphur (S_8) present in 16 g of solid sulphur.
11. Calculate the number of aluminium ions present in 0.051 g of aluminium oxide.

(*Hint:* The mass of an ion is the same as that of an atom of the same element. Atomic mass of Al = 27 u)

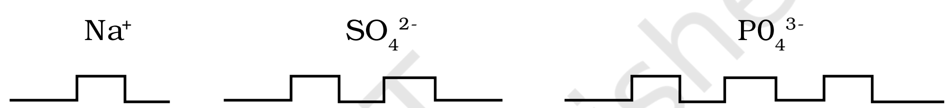
Group Activity

Play a game for writing formulae.

Example1 : Make placards with symbols and valencies of the elements separately. Each student should hold two placards, one with the symbol in the right hand and the other with the valency in the left hand. Keeping the symbols in place, students should criss-cross their valencies to form the formula of a compound.

Example 2 : A low cost model for writing formulae: Take empty blister packs of medicines. Cut them in groups, according to the valency of the element, as shown in the figure. Now, you can make formulae by fixing one type of ion into other.

For example:



Formula for sodium sulphate:

2 sodium ions can be fixed on one sulphate ion.

Hence, the formula will be: Na_2SO_4

Do it yourself :

Now, write the formula of sodium phosphate.

Chapter 4

STRUCTURE OF THE ATOM

In Chapter 3, we have learnt that atoms and molecules are the fundamental building blocks of matter. The existence of different kinds of matter is due to different atoms constituting them. Now the questions arise: (i) What makes the atom of one element different from the atom of another element? and (ii) Are atoms really indivisible, as proposed by Dalton, or are there smaller constituents inside the atom? We shall find out the answers to these questions in this chapter. We will learn about sub-atomic particles and the various models that have been proposed to explain how these particles are arranged within the atom.

A major challenge before the scientists at the end of the 19th century was to reveal the structure of the atom as well as to explain its important properties. The elucidation of the structure of atoms is based on a series of experiments.

One of the first indications that atoms are not indivisible, comes from studying static electricity and the condition under which electricity is conducted by different substances.

4.1 Charged Particles in Matter

For understanding the nature of charged particles in matter, let us carry out the following activities:

Activity 4.1

A. Comb dry hair. Does the comb then attract small pieces of paper?

B. Rub a glass rod with a silk cloth and bring the rod near an inflated balloon. Observe what happens.

From these activities, can we conclude that on rubbing two objects together, they become electrically charged? Where does this charge come from? This question can be answered by knowing that an atom is divisible and consists of charged particles.

Many scientists contributed in revealing the presence of charged particles in an atom.

It was known by 1900 that the atom was not a simple, indivisible particle but contained at least one sub-atomic particle – the electron identified by J.J. Thomson. Even before the electron was identified, E. Goldstein in 1886 discovered the presence of new radiations in a gas discharge and called them canal rays. These rays were positively charged radiations which ultimately led to the discovery of another sub-atomic particle. This sub-atomic particle had a charge, equal in magnitude but opposite in sign to that of the electron. Its mass was approximately 2000 times as that of the electron. It was given the name of proton. In general, an electron is represented as 'e^-' and a proton as 'p^+'. The mass of a proton is taken as one unit and its charge as plus one. The mass of an electron is considered to be negligible and its charge is minus one.

It seemed highly likely that an atom was composed of protons and electrons, mutually balancing their charges. It also appeared that the protons were in the interior of the atom, for whereas electrons could easily be peeled off but not protons. Now the big question was: what sort of structure did these particles of the atom form? We will find the answer to this question below.

Questions

1. *What are canal rays?*
2. *If an atom contains one electron and one proton, will it carry any charge or not?*

4.2 The Structure of an Atom

We have learnt Dalton's atomic theory in Chapter 3, which suggested that the atom was indivisible and indestructible. But the discovery of two fundamental particles (electrons and protons) inside the atom, led to the failure of this aspect of Dalton's atomic theory. It was then considered necessary to know how electrons and protons are arranged within an atom. For explaining this, many scientists proposed various atomic models. J.J. Thomson was the first one to propose a model for the structure of an atom.

4.2.1 Thomson's model of an atom

Thomson proposed the model of an atom to be similar to that of a Christmas pudding. The electrons, in a sphere of positive charge, were like currants (dry fruits) in a spherical Christmas pudding. We can also think of a watermelon, the positive charge in the atom is spread all over like the red edible part of the watermelon, while the electrons are studded in the positively charged sphere, like the seeds in the watermelon (Fig. 4.1).

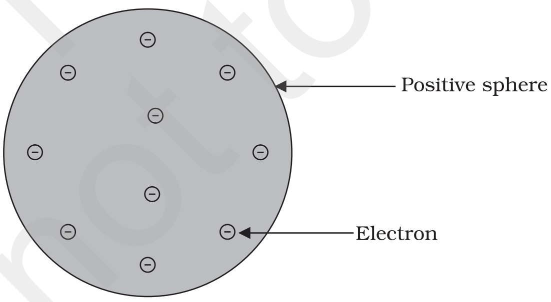


Fig.4.1: *Thomson's model of an atom*

J.J. Thomson (1856-1940), a British physicist, was born in Cheetham Hill, a suburb of Manchester, on 18 December 1856. He was awarded the Nobel prize in Physics in 1906 for his work on the discovery of electrons. He directed the Cavendish Laboratory at Cambridge for 35 years and seven of his research assistants subsequently won Nobel prizes.

Thomson proposed that:

(i) An atom consists of a positively charged sphere and the electrons are embedded in it.

(ii) The negative and positive charges are equal in magnitude. So, the atom as a whole is electrically neutral.

Although Thomson's model explained that atoms are electrically neutral, the results of experiments carried out by other scientists could not be explained by this model, as we will see below.

4.2.2 Rutherford's model of an atom

Ernest Rutherford was interested in knowing how the electrons are arranged within an atom. Rutherford designed an experiment for this. In this experiment, fast moving alpha (α)-particles were made to fall on a thin gold foil.

- He selected a gold foil because he wanted as thin a layer as possible. This gold foil was about 1000 atoms thick.
- α-particles are doubly-charged helium ions. Since they have a mass of 4 u, the fast-moving α-particles have a considerable amount of energy.
- It was expected that α-particles would be deflected by the sub-atomic particles in the gold atoms. Since the α-particles were much heavier than the protons, he did not expect to see large deflections.

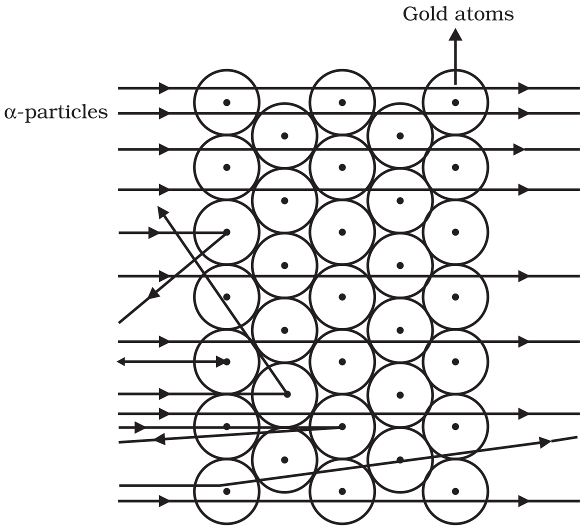


Fig. 4.2: *Scattering of α-particles by a gold foil*

But, the α-particle scattering experiment gave totally unexpected results (Fig. 4.2). The following observations were made:

(i) Most of the fast moving α-particles passed straight through the gold foil.

(ii) Some of the α-particles were deflected by the foil by small angles.

(iii) Surprisingly one out of every 12000 particles appeared to rebound.

In the words of Rutherford, "*This result was almost as incredible as if you fire a 15-inch shell at a piece of tissue paper and it comes back and hits you*".

E. Rutherford (1871-1937) was born at Spring Grove on 30 August 1871. He was known as the 'Father' of nuclear physics. He is famous for his work on radioactivity and the discovery of the nucleus of an atom with the gold foil experiment. He got the Nobel prize in chemistry in 1908.

Let us think of an activity in an open field to understand the implications of this experiment. Let a child stand in front of a wall with his eyes closed. Let him throw stones at the wall from a distance. He will hear a sound when each stone strikes the wall. If he repeats this ten times, he will hear the sound ten times. But if a blind-folded child were to throw stones at a barbed-wire fence, most of the stones would not hit the fencing and no sound would be heard. This is because there are lots of gaps in the fence which allow the stone to pass through them.

Following a similar reasoning, Rutherford concluded from the α-particle scattering experiment that–

(i) Most of the space inside the atom is empty because most of the α-particles passed through the gold foil without getting deflected.

(ii) Very few particles were deflected from their path, indicating that the positive charge of the atom occupies very little space.

(iii) A very small fraction of α-particles were deflected by 180^0, indicating that all the positive charge and mass of the gold atom were concentrated in a very small volume within the atom.

From the data he also calculated that the radius of the nucleus is about 10^5 times less than the radius of the atom.

On the basis of his experiment, Rutherford put forward the nuclear model of an atom, which had the following features:

(i) There is a positively charged centre in an atom called the nucleus. Nearly all the mass of an atom resides in the nucleus.

(ii) The electrons revolve around the nucleus in circular paths.

(iii) The size of the nucleus is very small as compared to the size of the atom.

Drawbacks of Rutherford's model of the atom

The revolution of the electron in a circular orbit is not expected to be stable. Any particle in a circular orbit would undergo acceleration. During acceleration, charged particles would radiate energy. Thus, the revolving electron would lose energy and finally fall into the nucleus. If this were so, the atom should be highly unstable and hence matter would not exist in the form that we know. We know that atoms are quite stable.

4.2.3 Bohr's model of atom

In order to overcome the objections raised against Rutherford's model of the atom, Neils Bohr put forward the following postulates about the model of an atom:

(i) Only certain special orbits known as discrete orbits of electrons, are allowed inside the atom.

(ii) While revolving in discrete orbits the electrons do not radiate energy.

Neils Bohr (1885-1962) was born in Copenhagen on 7 October 1885. He was appointed professor of physics at Copenhagen University in 1916. He got the Nobel prize for his work on the structure of atom in 1922. Among Professor Bohr's numerous writings, three appearing as books are:
(i) The Theory of Spectra and Atomic Constitution, (ii) Atomic Theory and, (iii) The Description of Nature.

These orbits or shells are called energy levels. Energy levels in an atom are shown in Fig. 4.3.

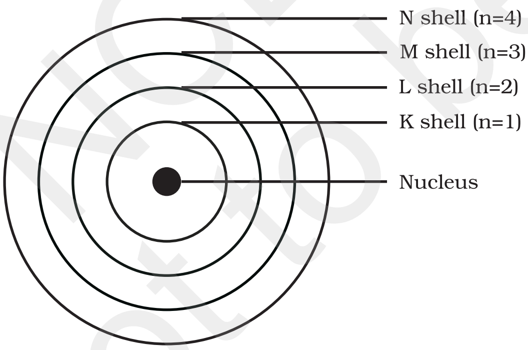


***Fig. 4.3:** A few energy levels in an atom*

These orbits or shells are represented by the letters K,L,M,N,… or the numbers, n=1,2,3,4,….

Questions

1. On the basis of Thomson's model of an atom, explain how the atom is neutral as a whole.

2. On the basis of Rutherford's model of an atom, which sub-atomic particle is present in the nucleus of an atom?

3. Draw a sketch of Bohr's model of an atom with three shells.

4. What do you think would be the observation if the α-particle scattering experiment is carried out using a foil of a metal other than gold?

4.2.4 Neutrons

In 1932, J. Chadwick discovered another sub-atomic particle which had no charge and a mass nearly equal to that of a proton. It was eventually named as neutron. Neutrons are present in the nucleus of all atoms, except hydrogen. In general, a neutron is represented as 'n'. The mass of an atom is therefore given by the sum of the masses of protons and neutrons present in the nucleus.

Questions

1. Name the three sub-atomic particles of an atom.

2. Helium atom has an atomic mass of 4 u and two protons in its nucleus. How many neutrons does it have?

4.3 How are Electrons Distributed in Different Orbits (Shells)?

The distribution of electrons into different orbits of an atom was suggested by Bohr and Bury.

The following rules are followed for writing the number of electrons in different energy levels or shells:

(i) The maximum number of electrons present in a shell is given by the

formula $2n^2$, where 'n' is the orbit number or energy level index, 1,2,3,.... Hence the maximum number of electrons in different shells are as follows:
first orbit or K-shell will be = $2 \times 1^2 = 2$, second orbit or L-shell will be = $2 \times 2^2 = 8$, third orbit or M-shell will be = $2 \times 3^2 = 18$, fourth orbit or N-shell will be = $2 \times 4^2 = 32$, and so on.

(ii) The maximum number of electrons that can be accommodated in the outermost orbit is 8.

(iii) Electrons are not accommodated in a given shell, unless the inner shells are filled. That is, the shells are filled in a step-wise manner.

Atomic structure of the first eighteen elements is shown schematically in Fig. 4.4.

- The composition of atoms of the first eighteen elements is given in Table 4.1.

Questions

1. *Write the distribution of electrons in carbon and sodium atoms.*
2. *If K and L shells of an atom are full, then what would be the total number of electrons in the atom?*

4.4 Valency

We have learnt how the electrons in an atom are arranged in different shells/orbits. The electrons present in the outermost shell of an atom are known as the valence electrons.

From the Bohr-Bury scheme, we also know that the outermost shell of an atom can

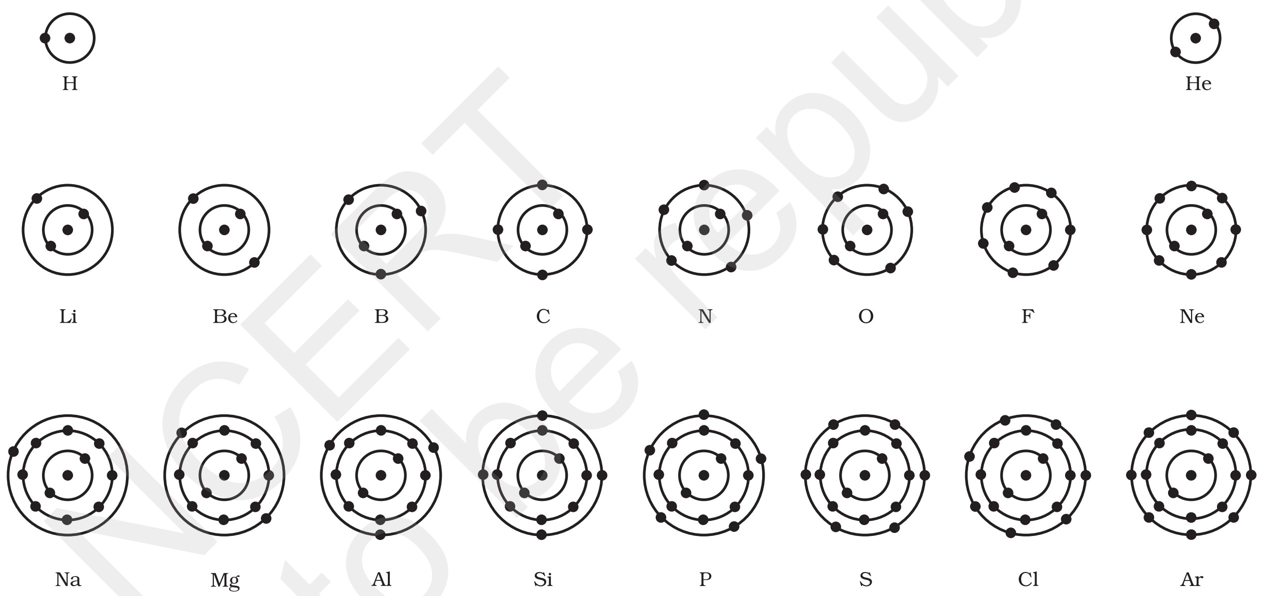


***Fig.4.4:** Schematic atomic structure of the first eighteen elements*

Activity 4.2

- Make a static atomic model displaying electronic configuration of the first eighteen elements.

accommodate a maximum of 8 electrons. It was observed that the atoms of elements, having a completely filled outermost shell show little chemical activity. In other words, their combining capacity or valency is zero. Of these inert elements, the helium atom has

Table 4.1: Composition of Atoms of the First Eighteen Elements with Electron Distribution in Various Shells

Name of Element	Symbol	Atomic Number	Number of Protons	Number of Neutrons	Number of Electrons	Distribution of Electrons				Vale-ncy
						K	L	M	N	
Hydrogen	H	1	1	-	1	1	-	-	-	1
Helium	He	2	2	2	2	2	-	-	-	0
Lithium	Li	3	3	4	3	2	1	-	-	1
Beryllium	Be	4	4	5	4	2	2	-	-	2
Boron	B	5	5	6	5	2	3	-	-	3
Carbon	C	6	6	6	6	2	4	-	-	4
Nitrogen	N	7	7	7	7	2	5	-	-	3
Oxygen	O	8	8	8	8	2	6	-	-	2
Fluorine	F	9	9	10	9	2	7	-	-	1
Neon	Ne	10	10	10	10	2	8	-	-	0
Sodium	Na	11	11	12	11	2	8	1	-	1
Magnesium	Mg	12	12	12	12	2	8	2	-	2
Aluminium	Al	13	13	14	13	2	8	3	-	3
Silicon	Si	14	14	14	14	2	8	4	-	4
Phosphorus	P	15	15	16	15	2	8	5	-	3,5
Sulphur	S	16	16	16	16	2	8	6	-	2
Chlorine	Cl	17	17	18	17	2	8	7	-	1
Argon	Ar	18	18	22	18	2	8	8		0

two electrons in its outermost shell and all other elements have atoms with eight electrons in the outermost shell.

The combining capacity of the atoms of other elements, that is, their tendency to react and form molecules with atoms of the same or different elements, was thus explained as an attempt to attain a fully-filled outermost shell. An outermost-shell, which had eight electrons was said to possess an octet. Atoms would thus react, so as to achieve an octet in the outermost shell. This was done by sharing, gaining or losing electrons. The number of electrons gained, lost or shared so as to make the octet of electrons in the outermost shell, gives us directly the combining capacity of the element, that is, the valency discussed in the previous chapter. For example, hydrogen/lithium/sodium atoms contain one electron each in their outermost shell, therefore each one of them can lose one electron. So, they are said to have valency of one. Can you tell, what is valency of magnesium and aluminium? It is two and three, respectively, because magnesium has two electrons in its outermost shell and aluminium has three electrons in its outermost shell.

If the number of electrons in the outermost shell of an atom is close to its full capacity, then valency is determined in a different way. For example, the fluorine atom has 7 electrons in the outermost shell, and its valency could be 7. But it is easier for fluorine to gain one electron instead of losing seven electrons. Hence, its valency is determined by subtracting seven electrons from the octet and this gives you a valency of one for fluorine. Valency can be calculated in a similar manner for oxygen. What is the valency of oxygen that you get from this calculation?

Therefore, an atom of each element has a definite combining capacity, called its valency. Valency of the first eighteen elements is given in the last column of Table 4.1.

Question

1. *How will you find the valency of chlorine, sulphur and magnesium?*

4.5 Atomic Number and Mass Number

4.5.1 Atomic number

We know that protons are present in the nucleus of an atom. It is the number of protons of an atom, which determines its atomic number. It is denoted by 'Z'. All atoms of an element have the same atomic number, Z. In fact, elements are defined by the number of protons they possess. For hydrogen, Z = 1, because in hydrogen atom, only one proton is present in the nucleus. Similarly, for carbon, Z = 6. Therefore, the atomic number is defined as the total number of protons present in the nucleus of an atom.

4.5.2 Mass number

After studying the properties of the sub-atomic particles of an atom, we can conclude that mass of an atom is practically due to protons and neutrons alone. These are present in the nucleus of an atom. Hence protons and neutrons are also called nucleons. Therefore, the mass of an atom resides in its nucleus. For example, mass of carbon is 12 u because it has 6 protons and 6 neutrons, 6 u + 6 u = 12 u. Similarly, the mass of aluminium is 27 u (13 protons+14 neutrons). The mass number is defined as the sum of the total number of protons and neutrons present in the nucleus of an atom. In the notation for an atom, the atomic number, mass number and symbol of the element are to be written as:

Mass Number

Symbol of element

Atomic Number

For example, nitrogen is written as $^{14}_{7}N$.

Questions

1. *If number of electrons in an atom is 8 and number of protons is also 8, then (i) what is the atomic number of the atom? and (ii) what is the charge on the atom?*
2. *With the help of Table 4.1, find out the mass number of oxygen and sulphur atom.*

4.6 Isotopes

In nature, a number of atoms of some elements have been identified, which have the same atomic number but different mass numbers. For example, take the case of hydrogen atom, it has three atomic species, namely protium ($^{1}_{1}H$), deuterium ($^{2}_{1}H$ or D) and tritium ($^{3}_{1}H$ or T). The atomic number of each one is 1, but the mass number is 1, 2 and 3, respectively. Other such examples are (i) carbon, $^{12}_{6}C$ and $^{14}_{6}C$, (ii) chlorine, $^{35}_{17}Cl$ and $^{37}_{17}Cl$, etc.

On the basis of these examples, isotopes are defined as the atoms of the same element, having the same atomic number but different mass numbers. Therefore, we can say that there are three isotopes of hydrogen atom, namely protium, deuterium and tritium.

Many elements consist of a mixture of isotopes. Each isotope of an element is a pure substance. The chemical properties of isotopes are similar but their physical properties are different.

Chlorine occurs in nature in two isotopic forms, with masses 35 u and 37 u in the ratio of 3:1. Obviously, the question arises: what should we take as the mass of chlorine atom? Let us find out.

The mass of an atom of any natural element is taken as the average mass of all the naturally occuring atoms of that element. If an element has no isotopes, then the mass of its atom would be the same as the sum of protons and neutrons in it. But if an element occurs in isotopic forms, then we have to know the percentage of each isotopic form and then the average mass is calculated.

The average atomic mass of chlorine atom, on the basis of above data, will be

$$35 \quad \frac{75}{100} \quad 37 \quad \frac{25}{100}$$

$$\frac{105}{4} \quad \frac{37}{4} \quad \frac{142}{4} \quad 35.5\,\text{u}$$

This does not mean that any one atom of chlorine has a fractional mass of 35.5 u. It means that if you take a certain amount of chlorine, it will contain both isotopes of chlorine and the average mass is 35.5 u.

Applications

Since the chemical properties of all the isotopes of an element are the same, normally we are not concerned about taking a mixture. But some isotopes have special properties which find them useful in various fields. Some of them are :

(i) An isotope of uranium is used as a fuel in nuclear reactors.

(ii) An isotope of cobalt is used in the treatment of cancer.

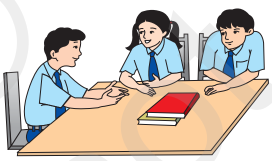
(iii) An isotope of iodine is used in the treatment of goitre.

4.6.1 Isobars

Let us consider two elements — calcium, atomic number 20, and argon, atomic number 18. The number of electrons in these atoms is different, but the mass number of both these elements is 40. That is, the total number of nucleons is the same in the atoms of this pair of elements. Atoms of different elements with different atomic numbers, which have the same mass number, are known as isobars.

Questions

1. *For the symbol H,D and T tabulate three sub-atomic particles found in each of them.*
2. *Write the electronic configuration of any one pair of isotopes and isobars.*



What you have learnt

- Credit for the discovery of electron and proton goes to J.J. Thomson and E.Goldstein, respectively.
- J.J. Thomson proposed that electrons are embedded in a positive sphere.

- Rutherford's alpha-particle scattering experiment led to the discovery of the atomic nucleus.
- Rutherford's model of the atom proposed that a very tiny nucleus is present inside the atom and electrons revolve around this nucleus. The stability of the atom could not be explained by this model.
- Neils Bohr's model of the atom was more successful. He proposed that electrons are distributed in different shells with discrete energy around the nucleus. If the atomic shells are complete, then the atom will be stable and less reactive.
- J. Chadwick discovered presence of neutrons in the nucleus of an atom. So, the three sub-atomic particles of an atom are: (i) electrons, (ii) protons and (iii) neutrons. Electrons are negatively charged, protons are positively charged and neutrons have no charges. The mass of an electron is about $\frac{1}{2000}$ times the mass of an hydrogen atom. The mass of a proton and a neutron is taken as one unit each.
- Shells of an atom are designated as K,L,M,N,....
- Valency is the combining capacity of an atom.
- The atomic number of an element is the same as the number of protons in the nucleus of its atom.
- The mass number of an atom is equal to the number of nucleons in its nucleus.
- Isotopes are atoms of the same element, which have different mass numbers.
- Isobars are atoms having the same mass number but different atomic numbers.
- Elements are defined by the number of protons they possess.

Exercises

1. Compare the properties of electrons, protons and neutrons.
2. What are the limitations of J.J. Thomson's model of the atom?
3. What are the limitations of Rutherford's model of the atom?
4. Describe Bohr's model of the atom.
5. Compare all the proposed models of an atom given in this chapter.
6. Summarise the rules for writing of distribution of electrons in various shells for the first eighteen elements.
7. Define valency by taking examples of silicon and oxygen.

8. Explain with examples (i) Atomic number, (ii) Mass number, (iii) Isotopes and iv) Isobars. Give any two uses of isotopes.
9. Na^+ has completely filled K and L shells. Explain.
10. If bromine atom is available in the form of, say, two isotopes $^{79}_{35}Br$ (49.7%) and $^{81}_{35}Br$ (50.3%), calculate the average atomic mass of bromine atom.
11. The average atomic mass of a sample of an element X is 16.2 u. What are the percentages of isotopes $^{16}_{8}X$ and $^{18}_{8}X$ in the sample?
12. If Z = 3, what would be the valency of the element? Also, name the element.
13. Composition of the nuclei of two atomic species X and Y are given as under

		X	Y
Protons	=	6	6
Neutrons	=	6	8

Give the mass numbers of X and Y. What is the relation between the two species?
14. For the following statements, write T for True and F for False.
    (a) J.J. Thomson proposed that the nucleus of an atom contains only nucleons.
    (b) A neutron is formed by an electron and a proton combining together. Therefore, it is neutral.
    (c) The mass of an electron is about $\frac{1}{2000}$ times that of proton.
    (d) An isotope of iodine is used for making tincture iodine, which is used as a medicine.

Put tick (✓) against correct choice and cross (×) against wrong choice in questions 15, 16 and 17

15. Rutherford's alpha-particle scattering experiment was responsible for the discovery of
    (a) Atomic Nucleus (b) Electron
    (c) Proton (d) Neutron
16. Isotopes of an element have
    (a) the same physical properties
    (b) different chemical properties
    (c) different number of neutrons
    (d) different atomic numbers.
17. Number of valence electrons in Cl^- ion are:
    (a) 16 (b) 8 (c) 17 (d) 18

18. Which one of the following is a correct electronic configuration of sodium?

(a) 2,8 (b) 8,2,1 (c) 2,1,8 (d) 2,8,1.

19. Complete the following table.

Atomic Number	Mass Number	Number of Neutrons	Number of Protons	Number of Electrons	Name of the Atomic Species
9	-	10	-	-	-
16	32	-	-	-	Sulphur
-	24	-	12	-	-
-	2	-	1	-	-
-	1	0	1	0	-

Chapter 5

The Fundamental Unit of Life

While examining a thin slice of cork, Robert Hooke saw that the cork resembled the structure of a honeycomb consisting of many little compartments. Cork is a substance which comes from the bark of a tree. This was in the year 1665 when Hooke made this chance observation through a self-designed microscope. Robert Hooke called these boxes cells. Cell is a Latin word for 'a little room'.

This may seem to be a very small and insignificant incident but it is very important in the history of science. This was the very first time that someone had observed that living things appear to consist of separate units. The use of the word 'cell' to describe these units is used till this day in biology.

Let us find out about cells.

5.1 What are Living Organisms Made Up of?

Activity 5.1

- Let us take a small piece from an onion bulb. With the help of a pair of forceps, we can peel off the skin (called epidermis) from the concave side (inner layer) of the onion. This layer can be put immediately in a watch-glass containing water. This will prevent the peel from getting folded or getting dry. What do we do with this peel?
- Let us take a glass slide, put a drop of water on it and transfer a small piece of the peel from the watch glass to the slide. Make sure that the peel is perfectly flat on the slide. A thin camel hair paintbrush might be necessary to help transfer the peel. Now we put a drop of safranin solution on this piece followed by a cover slip. Take care to avoid air bubbles while putting the cover slip with the help of a mounting needle. Ask your teacher for help. We have prepared a temporary mount of onion peel. We can observe this slide under low power followed by high powers of a compound microscope.

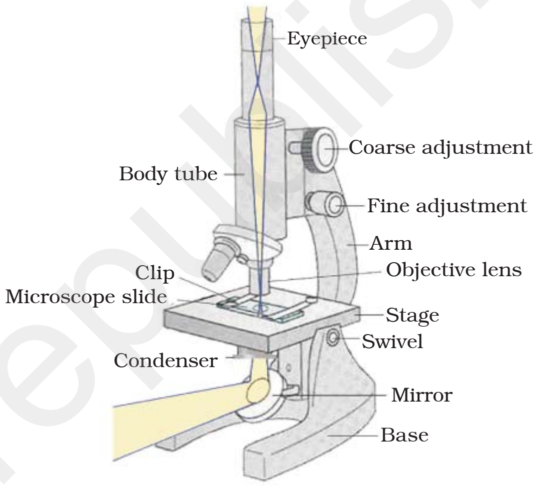


Fig. 5.1: *Compound microscope*

What do we observe as we look through the lens? Can we draw the structures that we are able to see through the microscope, on an observation sheet? Does it look like Fig. 5.2?

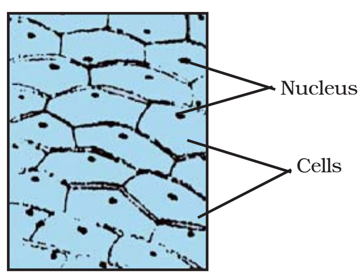


Fig. 5.2: *Cells of an onion peel*

We can try preparing temporary mounts of peels of onions of different sizes. What do we observe? Do we see similar structures or different structures?

What are these structures?

These structures look similar to each other. Together they form a big structure like an onion bulb! We find from this activity that onion bulbs of different sizes have similar small structures visible under a microscope. The cells of the onion peel will all look the same, regardless of the size of the onion they came from.

These small structures that we see are the basic building units of the onion bulb. These structures are called cells. Not only onions, but all organisms that we observe around are made up of cells. However, there are also single cells that live on their own.

More to know

Cells were first discovered by Robert Hooke in 1665. He observed the cells in a cork slice with the help of a primitive microscope. Leeuwenhoek (1674), with the improved microscope, discovered the free living cells in pond water for the first time. It was Robert Brown in 1831 who discovered the nucleus in the cell. Purkinje in 1839 coined the term 'protoplasm' for the fluid substance of the cell. The cell theory, that all the plants and animals are composed of cells and that the cell is the basic unit of life, was presented by two biologists, Schleiden (1838) and Schwann (1839). The cell theory was further expanded by Virchow (1855) by suggesting that all cells arise from pre-existing cells. With the discovery of the electron microscope in 1940, it was possible to observe and understand the complex structure of the cell and its various organelles.

The invention of magnifying lenses led to the discovery of the microscopic world. It is now known that a single cell may constitute a whole organism as in *Amoeba*, *Chlamydomonas*, *Paramoecium* and bacteria. These organisms are called unicellular organisms (uni = single). On the other hand, many cells group together in a single body and assume different functions in it to form various body parts in multicellular organisms (multi = many) such as some fungi, plants and animals. Can we find out names of some more unicellular organisms?

Every multi-cellular organism has come from a single cell. How? Cells divide to produce cells of their own kind. All cells thus come from pre-existing cells.

Activity 5.2

- We can try preparing temporary mounts of leaf peels, tip of roots of onion or even peels of onions of different sizes.
- After performing the above activity, let us see what the answers to the following questions would be:
  (a) Do all cells look alike in terms of shape and size?
  (b) Do all cells look alike in structure?
  (c) Could we find differences among cells from different parts of a plant body?
  (d) What similarities could we find?

Some organisms can also have cells of different kinds. Look at the following picture. It depicts some cells from the human body.

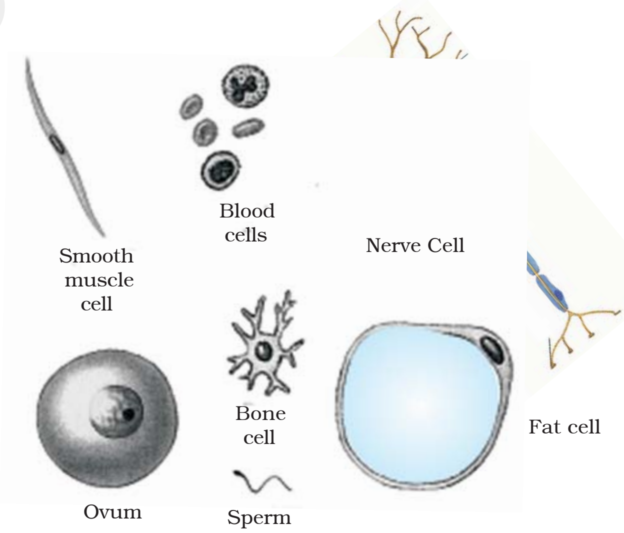


***Fig. 5.3:** Various cells from the human body*

The shape and size of cells are related to the specific function they perform. Some cells like *Amoeba* have changing shapes. In some cases the cell shape could be more or less fixed and peculiar for a particular type of cell; for example, nerve cells have a typical shape.

Each living cell has the capacity to perform certain basic functions that are characteristic of all living forms. How does a living cell perform these basic functions? We know that there is a division of labour in multicellular organisms such as human beings. This means that different parts of the human body perform different functions. The human body has a heart to pump blood, a stomach to digest food and so on. Similarly, division of labour is also seen within a single cell. In fact, each such cell has got certain specific components within it known as cell organelles. Each kind of cell organelle performs a special function, such as making new material in the cell, clearing up the waste material from the cell and so on. A cell is able to live and perform all its functions because of these organelles. These organelles together constitute the basic unit called the cell. It is interesting that all cells are found to have the same organelles, no matter what their function is or what organism they are found in.

Questions

1. *Who discovered cells, and how?*
2. *Why is the cell called the structural and functional unit of life?*

5.2 What is a Cell Made Up of? What is the Structural Organisation of a Cell?

We saw above that the cell has special components called organelles. How is a cell organised?

If we study a cell under a microscope, we would come across three features in almost every cell; plasma membrane, nucleus and cytoplasm. All activities inside the cell and interactions of the cell with its environment are possible due to these features. Let us see how.

5.2.1 Plasma membrane or cell membrane

This is the outermost covering of the cell that separates the contents of the cell from its external environment. The plasma membrane allows or permits the entry and exit of some materials in and out of the cell. It also prevents movement of some other materials. The cell membrane, therefore, is called a selectively permeable membrane.

How does the movement of substances take place into the cell? How do substances move out of the cell?

Some substances like carbon dioxide or oxygen can move across the cell membrane by a process called diffusion. We have studied the process of diffusion in earlier chapters. We saw that there is spontaneous movement of a substance from a region of high concentration to a region where its concentration is low.

Something similar to this happens in cells when, for example, some substance like CO_2 (which is cellular waste and requires to be excreted out by the cell) accumulates in high concentrations inside the cell. In the cell's external environment, the concentration of CO_2 is low as compared to that inside the cell. As soon as there is a difference of concentration of CO_2 inside and outside a cell, CO_2 moves out of the cell, from a region of high concentration, to a region of low concentration outside the cell by the process of diffusion. Similarly, O_2 enters the cell by the process of diffusion when the level or concentration of O_2 inside the cell decreases. Thus, diffusion plays an important role in gaseous exchange between the cells as well as the cell and its external environment.

Water also obeys the law of diffusion. The movement of water molecules through such a selectively permeable membrane is called osmosis. The movement of water across the plasma membrane is also affected by the amount of substance dissolved in water. Thus, osmosis is the passage of water from a region of high water concentration through a semi-permeable membrane to a region of low water concentration.

What will happen if we put an animal cell or a plant cell into a solution of sugar or salt in water?

One of the following three things could happen:

1. If the medium surrounding the cell has a higher water concentration than the cell, meaning that the outside solution is very dilute, the cell will gain water by osmosis. Such a solution is known as a hypotonic solution.

   Water molecules are free to pass across the cell membrane in both directions, but more water will come into the cell than will leave. The net (overall) result is that water enters the cell. The cell is likely to swell up.
2. If the medium has exactly the same water concentration as the cell, there will be no net movement of water across the cell membrane. Such a solution is known as an isotonic solution.

   Water crosses the cell membrane in both directions, but the amount going in is the same as the amount going out, so there is no overall movement of water. The cell will stay the same size.
3. If the medium has a lower concentration of water than the cell, meaning that it is a very concentrated solution, the cell will lose water by osmosis. Such a solution is known as a hypertonic solution.

   Again, water crosses the cell membrane in both directions, but this time more water leaves the cell than enters it. Therefore the cell will shrink.

Thus, osmosis is a special case of diffusion through a selectively permeable membrane. Now let us try out the following activity:

Activity 5.3

Osmosis with an egg

(a) Remove the shell of an egg by dissolving it in dilute hydrochloric acid. The shell is mostly calcium carbonate. A thin outer skin now encloses the egg. Put the egg in pure water and observe after 5 minutes. What do we observe?
The egg swells because water passes into it by osmosis.

(b) Place a similar de-shelled egg in a concentrated salt solution and observe for 5 minutes. The egg shrinks. Why?
Water passes out of the egg solution into the salt solution because the salt solution is more concentrated.

We can also try a similar activity with dried raisins or apricots.

Activity 5.4

- Put dried raisins or apricots in plain water and leave them for some time. Then place them into a concentrated solution of sugar or salt. You will observe the following:

(a) Each gains water and swells when placed in water.

(b) However, when placed in the concentrated solution it loses water, and consequently shrinks.

Unicellular freshwater organisms and most plant cells tend to gain water through osmosis. Absorption of water by plant roots is also an example of osmosis.

Thus, diffusion is important in exhange of gases and water in the life of a cell. In additions to this, the cell also obtains nutrition from its environment. Different molecules move in and out of the cell through a type of transport requiring use of energy.

The plasma membrane is flexible and is made up of organic molecules called lipids and proteins. However, we can observe the structure of the plasma membrane only through an electron microscope.

The flexibility of the cell membrane also enables the cell to engulf in food and other material from its external environment. Such processes are known as endocytosis. *Amoeba* acquires its food through such processes.

Activity _____ 5.5

- Find out about electron microscopes from resources in the school library or through the internet. Discuss it with your teacher.

Questions

1. *How do substances like CO_2 and water move in and out of the cell? Discuss.*
2. *Why is the plasma membrane called a selectively permeable membrane?*

5.2.2 Cell wall

Plant cells, in addition to the plasma membrane, have another rigid outer covering called the cell wall. The cell wall lies outside the plasma membrane. The plant cell wall is mainly composed of cellulose. Cellulose is a complex substance and provides structural strength to plants.

When a living plant cell loses water through osmosis there is shrinkage or contraction of the contents of the cell away from the cell wall. This phenomenon is known as plasmolysis. We can observe this phenomenon by performing the following activity:

Activity _____ 5.6

- Mount the peel of a Rheo leaf in water on a slide and examine cells under the high power of a microscope. Note the small green granules, called chloroplasts. They contain a green substance called chlorophyll. Put a strong solution of sugar or salt on the mounted leaf on the slide. Wait for a minute and observe under a microscope. What do we see?
- Now place some Rheo leaves in boiling water for a few minutes. This kills the cells. Then mount one leaf on a slide and observe it under a microscope. Put a strong solution of sugar or salt on the mounted leaf on the slide. Wait for a minute and observe it again. What do we find? Did plasmolysis occur now?

What do we infer from this activity? It appears that only living cells, and not dead cells, are able to absorb water by osmosis.

Cell walls permit the cells of plants, fungi and bacteria to withstand very dilute (hypotonic) external media without bursting. In such media the cells tend to take up water by osmosis. The cell swells, building up pressure against the cell wall. The wall exerts an equal pressure against the swollen cell. Because of their walls, such cells can withstand much greater changes in the surrounding medium than animal cells.

5.2.3 Nucleus

Remember the temporary mount of onion peel we prepared? We had put iodine solution on the peel. Why? What would we see if we tried observing the peel without putting the iodine solution? Try it and see what the difference is. Further, when we put iodine solution on the peel, did each cell get evenly coloured?

According to their chemical composition different regions of cells get coloured differentially. Some regions appear darker than other regions. Apart from iodine solution we could also use safranin solution or methylene blue solution to stain the cells.

We have observed cells from an onion; let us now observe cells from our own body.

Activity _____ 5.7

- Let us take a glass slide with a drop of water on it. Using an ice-cream spoon gently scrape the inside surface of the cheek. Does any material get stuck on the spoon? With the help of a needle we can transfer this material and spread it evenly on the glass slide kept ready for this. To colour the material we can put a drop of methylene blue solution on it. Now the material is ready for observation under microscope. Do not forget to put a cover-slip on it!
- What do we observe? What is the shape of the cells we see? Draw it on the observation sheet.

- Was there a darkly coloured, spherical or oval, dot-like structure near the centre of each cell? This structure is called nucleus. Were there similar structures in onion peel cells?

The nucleus has a double layered covering called nuclear membrane. The nuclear membrane has pores which allow the transfer of material from inside the nucleus to its outside, that is, to the cytoplasm (which we will talk about in section 5.2.4).

The nucleus contains chromosomes, which are visible as rod-shaped structures only when the cell is about to divide. Chromosomes contain information for inheritance of features from parents to next generation in the form of DNA (Deoxyribo Nucleic Acid) molecules. Chromosomes are composed of DNA and protein. DNA molecules contain the information necessary for constructing and organising cells. Functional segments of DNA are called genes. In a cell which is not dividing, this DNA is present as part of chromatin material. Chromatin material is visible as entangled mass of thread like structures. Whenever the cell is about to divide, the chromatin material gets organised into chromosomes.

The nucleus plays a central role in cellular reproduction, the process by which a single cell divides and forms two new cells. It also plays a crucial part, along with the environment, in determining the way the cell will develop and what form it will exhibit at maturity, by directing the chemical activities of the cell.

In some organisms like bacteria, the nuclear region of the cell may be poorly defined due to the absence of a nuclear membrane. Such an undefined nuclear region containing only nucleic acids is called a nucleoid. Such organisms, whose cells lack a nuclear membrane, are called prokaryotes (Pro = primitive or primary; karyote ≈ karyon = nucleus). Organisms with cells having a nuclear membrane are called eukaryotes.

Prokaryotic cells (see Fig. 5.4) also lack most of the other cytoplasmic organelles present in eukaryotic cells. Many of the functions of such organelles are also performed by poorly organised parts of the cytoplasm (see section 5.2.4). The chlorophyll in photosynthetic prokaryotic bacteria is associated with membranous vesicles (bag like structures) but not with plastids as in eukaryotic cells (see section 5.2.5).

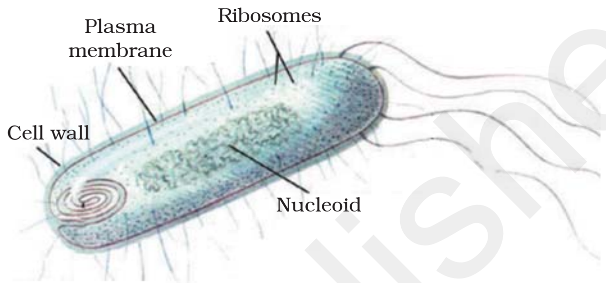


Fig. 5.4: *Prokaryotic cell*

5.2.4 CYTOPLASM

When we look at the temporary mounts of onion peel as well as human cheek cells, we can see a large region of each cell enclosed by the cell membrane. This region takes up very little stain. It is called the cytoplasm. The cytoplasm is the fluid content inside the plasma membrane. It also contains many specialised cell organelles. Each of these organelles performs a specific function for the cell.

Cell organelles are enclosed by membranes. In prokaryotes, beside the absence of a defined nuclear region, the membrane-bound cell organelles are also absent. On the other hand, the eukaryotic cells have nuclear membrane as well as membrane-enclosed organelles.

The significance of membranes can be illustrated with the example of viruses. Viruses lack any membranes and hence do not show characteristics of life until they enter a living body and use its cell machinery to multiply.

Question

1. Fill in the gaps in the following table illustrating differences between prokaryotic and eukaryotic cells.

Prokaryotic Cell	Eukaryotic Cell
1. Size : generally small (1-10 μm) 1 μm = 10^{-6} m	1. Size: generally large (5-100 μm)
2. Nuclear region: ______________ ______________ and known as__	2. Nuclear region: well defined and surrounded by a nuclear membrane
3. Chromosome: single	3. More than one chromosome
4. Membrane-bound cell organelles absent	4. ______________ ______________ ______________

5.2.5 Cell organelles

Every cell has a membrane around it to keep its own contents separate from the external environment. Large and complex cells, including cells from multicellular organisms, need a lot of chemical activities to support their complicated structure and function. To keep these activities of different kinds separate from each other, these cells use membrane-bound little structures (or 'organelles') within themselves. This is one of the features of the eukaryotic cells that distinguish them from prokaryotic cells. Some of these organelles are visible only with an electron microscope.

We have talked about the nucleus in a previous section. Some important examples of cell organelles which we will discuss now are: endoplasmic reticulum, Golgi apparatus, lysosomes, mitochondria, plastids and vacuoles. They are important because they carry out some very crucial functions in cells.

5.2.5 (i) Endoplasmic reticulum (ER)

The endoplasmic reticulum (ER) is a large network of membrane-bound tubes and sheets. It looks like long tubules or round or oblong bags (vesicles). The ER membrane is similar in structure to the plasma membrane. There are two types of ER– rough endoplasmic reticulum (RER) and smooth endoplasmic reticulum (SER). RER looks rough under a microscope because it has particles called ribosomes attached to its surface. The ribosomes, which are present in all active cells, are the sites of protein manufacture. The manufactured proteins are then sent to various places in the cell depending on need, using the ER. The SER helps in the manufacture of fat molecules, or lipids, important for cell function. Some of these proteins and lipids help in building the cell membrane. This process is known as membrane biogenesis. Some other proteins and lipids function as enzymes and hormones. Although the ER varies greatly in appearance in different cells, it always forms a network system.

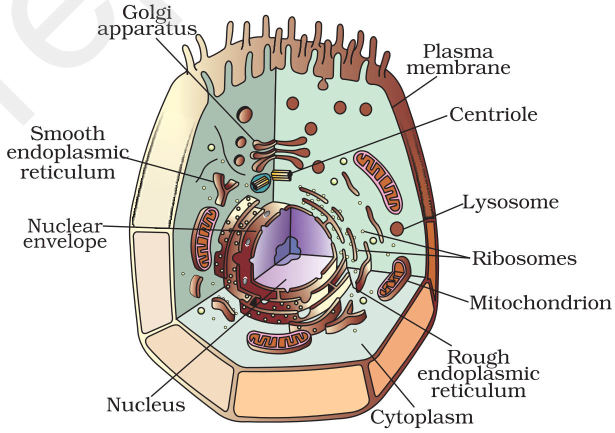


Fig. 5.5: *Animal cell*

Thus, one function of the ER is to serve as channels for the transport of materials (especially proteins) between various regions of the cytoplasm or between the cytoplasm and the nucleus. The ER also functions as a cytoplasmic framework providing a surface for some of the biochemical activities of the cell. In the liver cells of the group of animals called vertebrates (see Chapter 7), SER plays a crucial role in detoxifying many poisons and drugs.

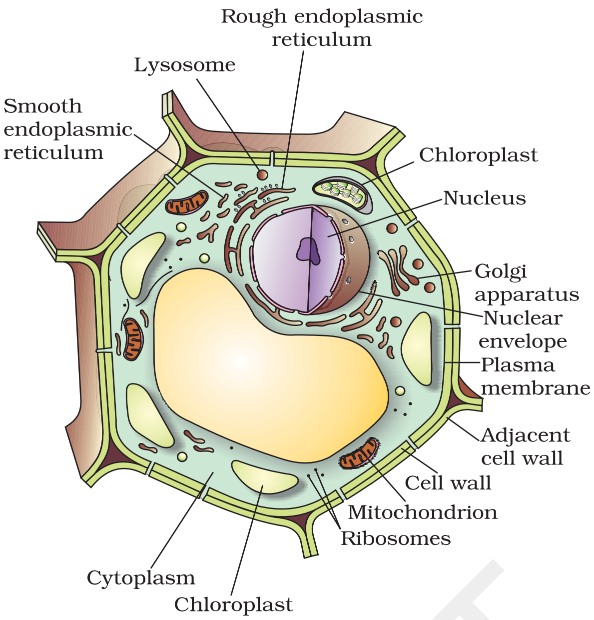
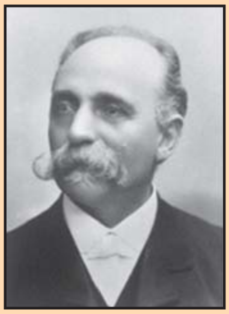


Fig. 5.6: *Plant cell*

5.2.5 (ii) GOLGI APPARATUS

The Golgi apparatus, first described by Camillo Golgi, consists of a system of membrane-bound vesicles arranged approximately parallel to each other in stacks called cisterns. These membranes often have connections with the membranes of ER and therefore constitute another portion of a complex cellular membrane system.

The material synthesised near the ER is packaged and dispatched to various targets inside and outside the cell through the Golgi apparatus. Its functions include the storage, modification and packaging of products in vesicles. In some cases, complex sugars may be made from simple sugars in the Golgi apparatus. The Golgi apparatus is also involved in the formation of lysosomes [see 5.2.5 (iii)].



Camillo Golgi was born at Corteno near Brescia in 1843. He studied medicine at the University of Pavia. After graduating in 1865, he continued to work in Pavia at the Hospital of St. Matteo. At that time most of his investigations were concerned with the nervous system, In 1872 he accepted the post of Chief Medical Officer at the Hospital for the Chronically Sick at Abbiategrasso. He first started his investigations into the nervous system in a little kitchen of this hospital, which he had converted into a laboratory. However, the work of greatest importance, which Golgi carried out was a revolutionary method of staining individual nerve and cell structures. This method is referred to as the 'black reaction'. This method uses a weak solution of silver nitrate and is particularly valuable in tracing the processes and most delicate ramifications of cells. All through his life, he continued to work on these lines, modifying and improving this technique. Golgi received the highest honours and awards in recognition of his work. He shared the Nobel prize in 1906 with Santiago Ramony Cajal for their work on the structure of the nervous system.

5.2.5 (iii) LYSOSOMES

Lysosomes are a kind of waste disposal system of the cell. Lysosomes help to keep the cell clean by digesting any foreign material as well as worn-out cell organelles. Foreign materials entering the cell, such as bacteria or food, as well as old organelles end up in the lysosomes, which break them up into small pieces. Lysosomes are able to do this because they contain powerful digestive enzymes capable of breaking down all organic material. During the disturbance in cellular metabolism, for example, when the cell gets damaged, lysosomes may burst and the enzymes digest their own cell. Therefore, lysosomes are also known as the 'suicide bags' of a cell. Structurally, lysosomes are membrane-bound sacs filled with digestive enzymes. These enzymes are made by RER.

5.2.5 (iv) Mitochondria

Mitochondria are known as the powerhouses of the cell. The energy required for various chemical activities needed for life is released by mitochondria in the form of ATP (Adenosine triphopshate) molecules. ATP is known as the energy currency of the cell. The body uses energy stored in ATP for making new chemical compounds and for mechanical work. Mitochondria have two membrane coverings instead of just one. The outer membrane is very porous while the inner membrane is deeply folded. These folds create a large surface area for ATP-generating chemical reactions.

Mitochondria are strange organelles in the sense that they have their own DNA and ribosomes. Therefore, mitochondria are able to make some of their own proteins.

5.2.5 (v) Plastids

Plastids are present only in plant cells. There are two types of plastids – chromoplasts (coloured plastids) and leucoplasts (white or colourless plastids). Plastids containing the pigment chlorophyll are known as chloroplasts. Chloroplasts are important for photosynthesis in plants. Chloroplasts also contain various yellow or orange pigments in addition to chlorophyll. Leucoplasts are primarily organelles in which materials such as starch, oils and protein granules are stored.

The internal organisation of the plastids consists of numerous membrane layers embedded in a material called the stroma. Plastids are similar to mitochondria in external structure. Like the mitochondria, plastids also have their own DNA and ribosomes.

5.2.5 (vi) Vacuoles

Vacuoles are storage sacs for solid or liquid contents. Vacuoles are small sized in animal cells while plant cells have very large vacuoles. The central vacuole of some plant cells may occupy 50-90% of the cell volume.

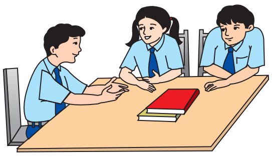
In plant cells vacuoles are full of cell sap and provide turgidity and rigidity to the cell. Many substances of importance in the life of the plant cell are stored in vacuoles. These include amino acids, sugars, various organic acids and some proteins. In single-celled organisms like *Amoeba*, the food vacuole contains the food items that the *Amoeba* has consumed. In some unicellular organisms, specialised vacuoles also play important roles in expelling excess water and some wastes from the cell.

Questions

1. *Can you name the two organelles we have studied that contain their own genetic material?*
2. *If the organisation of a cell is destroyed due to some physical or chemical influence, what will happen?*
3. *Why are lysosomes known as suicide bags?*
4. *Where are proteins synthesised inside the cell?*

Each cell thus acquires its structure and ability to function because of the organisation of its membrane and organelles in specific ways. The cell thus has a basic structural organisation. This helps the cells to perform functions like respiration, obtaining nutrition, and clearing of waste material, or forming new proteins.

Thus, the cell is the fundamental structural unit of living organisms. It is also the basic functional unit of life.



What you have learnt

- The fundamental organisational unit of life is the cell.
- Cells are enclosed by a plasma membrane composed of lipids and proteins.
- The cell membrane is an active part of the cell. It regulates the movement of materials between the ordered interior of the cell and the outer environment.
- In plant cells, a cell wall composed mainly of cellulose is located outside the cell membrane.
- The presence of the cell wall enables the cells of plants, fungi and bacteria to exist in hypotonic media without bursting.
- The nucleus in eukaryotes is separated from the cytoplasm by double-layered membrane and it directs the life processes of the cell.
- The ER functions both as a passageway for intracellular transport and as a manufacturing surface.
- The Golgi apparatus consists of stacks of membrane-bound vesicles that function in the storage, modification and packaging of substances manufactured in the cell.
- Most plant cells have large membranous organelles called plastids, which are of two types – chromoplasts and leucoplasts.
- Chromoplasts that contain chlorophyll are called chloroplasts and they perform photosynthesis.
- The primary function of leucoplasts is storage.
- Most mature plant cells have a large central vacuole that helps to maintain the turgidity of the cell and stores important substances including wastes.
- Prokaryotic cells have no membrane-bound organelles, their chromosomes are composed of only nucleic acid, and they have only very small ribosomes as organelles.

Exercises

1. Make a comparison and write down ways in which plant cells are different from animal cells.
2. How is a prokaryotic cell different from a eukaryotic cell?
3. What would happen if the plasma membrane ruptures or breaks down?

4. What would happen to the life of a cell if there was no Golgi apparatus?
5. Which organelle is known as the powerhouse of the cell? Why?
6. Where do the lipids and proteins constituting the cell membrane get synthesised?
7. How does an *Amoeba* obtain its food?
8. What is osmosis?
9. Carry out the following osmosis experiment:

   Take four peeled potato halves and scoos each one out to make potato cups. One of these potato cups should be made from a boiled potato. Put each potato cup in a trough containing water. Now,

   (a) Keep cup A empty
   (b) Put one teaspoon sugar in cup B
   (c) Put one teaspoon salt in cup C
   (d) Put one teaspoon sugar in the boiled potato cup D.

   Keep these for two hours. Then observe the four potato cups and answer the following:

   (i) Explain why water gathers in the hollowed portion of B and C.
   (ii) Why is potato A necessary for this experiment?
   (iii) Explain why water does not gather in the hollowed out portions of A and D.

Chapter 6

TISSUES

From the last chapter, we recall that all living organisms are made of cells. In unicellular organisms, a single cell performs all basic functions. For example, in *Amoeba*, a single cell carries out movement, intake of food and respiratory gases, respiration and excretion. But in multi-cellular organisms there are millions of cells. Most of these cells are specialised to carry out a few functions. Each specialised function is taken up by a different group of cells. Since these cells carry out only a particular function, they do it very efficiently. In human beings, muscle cells contract and relax to cause movement, nerve cells carry messages, blood flows to transport oxygen, food, hormones and waste material and so on. In plants, vascular tissues conduct food and water from one part of the plant to other parts. So, multi-cellular organisms show division of labour. Cells specialising in one function are often grouped together in the body. This means that a particular function is carried out by a cluster of cells at a definite place in the body. This cluster of cells, called a tissue, is arranged and designed so as to give the highest possible efficiency of function. Blood, phloem and muscle are all examples of tissues.

A group of cells that are similar in structure and/or work together to achieve a particular function forms a tissue.

6.1 Are Plants and Animals Made of Same Types of Tissues?

Let us compare their structure and functions. Do plants and animals have the same structure? Do they both perform similar functions?

There are noticeable differences between the two. Plants are stationary or fixed – they don't move. Most of the tissues they have are supportive, which provides them with structural strength. Most of these tissues are dead, since dead cells can provide mechanical strength as easily as live ones, and need less maintenance.

Animals on the other hand move around in search of food, mates and shelter. They consume more energy as compared to plants. Most of the tissues they contain are living.

Another difference between animals and plants is in the pattern of growth. The growth in plants is limited to certain regions, while this is not so in animals. There are some tissues in plants that divide throughout their life. These tissues are localised in certain regions. Based on the dividing capacity of the tissues, various plant tissues can be classified as growing or meristematic tissue and permanent tissue. Cell growth in animals is more uniform. So, there is no such demarcation of dividing and non-dividing regions in animals.

The structural organisation of organs and organ systems is far more specialised and localised in complex animals than even in very complex plants. This fundamental difference reflects the different modes of life pursued by these two major groups of organisms, particularly in their different feeding methods. Also, they are differently adapted for a sedentary existence on one hand (plants) and active locomotion on the other (animals), contributing to this difference in organ system design.

It is with reference to these complex animal and plant bodies that we will now talk about the concept of tissues in some detail.

Questions

1. *What is a tissue?*
2. *What is the utility of tissues in multi-cellular organisms?*

6.2 Plant Tissues

6.2.1 Meristematic tissue

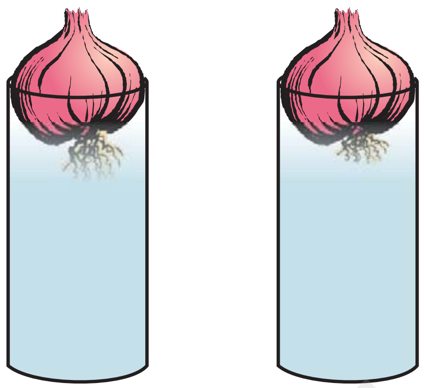


Fig. 6.1: *Growth of roots in onion bulbs*

Activity 6.1

- Take two glass jars and fill them with water.
- Now, take two onion bulbs and place one on each jar, as shown in Fig. 6.1.
- Observe the growth of roots in both the bulbs for a few days.
- Measure the length of roots on day 1, 2 and 3.
- On day 4, cut the root tips of the onion bulb in jar 2 by about 1 cm. After this, observe the growth of roots in both the jars and measure their lengths each day for five more days and record the observations in tables, like the table below:

Length	Day 1	Day 2	Day 3	Day 4	Day 5
Jar 1					
Jar 2					

- From the above observations, answer the following questions:
  1. Which of the two onions has longer roots? Why?
  2. Do the roots continue growing even after we have removed their tips?
  3. Why would the tips stop growing in jar 2 after we cut them?

The growth of plants occurs only in certain specific regions. This is because the dividing tissue, also known as meristematic tissue, is located only at these points. Depending on the region where they are present, meristematic tissues are classified as apical, lateral and intercalary (Fig. 6.2). New cells produced by meristem are initially like those of meristem itself, but as they grow and mature, their characteristics slowly change and they become differentiated as components of other tissues.

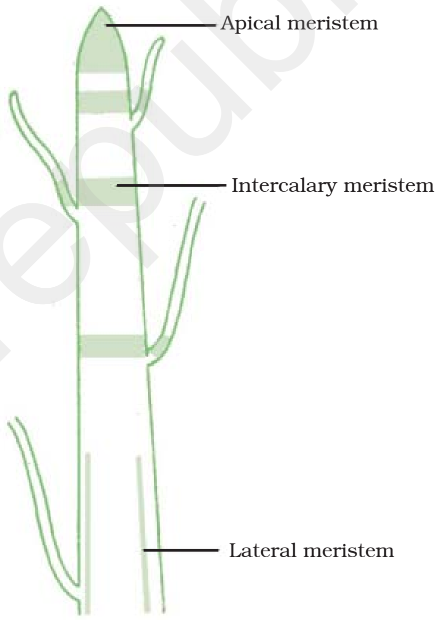


Fig. 6.2: *Location of meristematic tissue in plant body*

Apical meristem is present at the growing tips of stems and roots and increases the length of the stem and the root. The girth of the stem or root increases due to lateral meristem (cambium). Intercalary meristem is the meristem at the base of the leaves or internodes (on either side of the node) on twigs.

As the cells of this tissue are very active, they have dense cytoplasm, thin cellulose walls and prominent nuclei. They lack vacuoles. Can we think why they would lack vacuoles? (You might want to refer to the functions of vacuoles in the chapter on cells.)

6.2.2 Permanent tissue

What happens to the cells formed by meristematic tissue? They take up a specific role and lose the ability to divide. As a result, they form a permanent tissue. This process of taking up a permanent shape, size, and a function is called differentiation. Cells of meristematic tissue differentiate to form different types of permanent tissue.

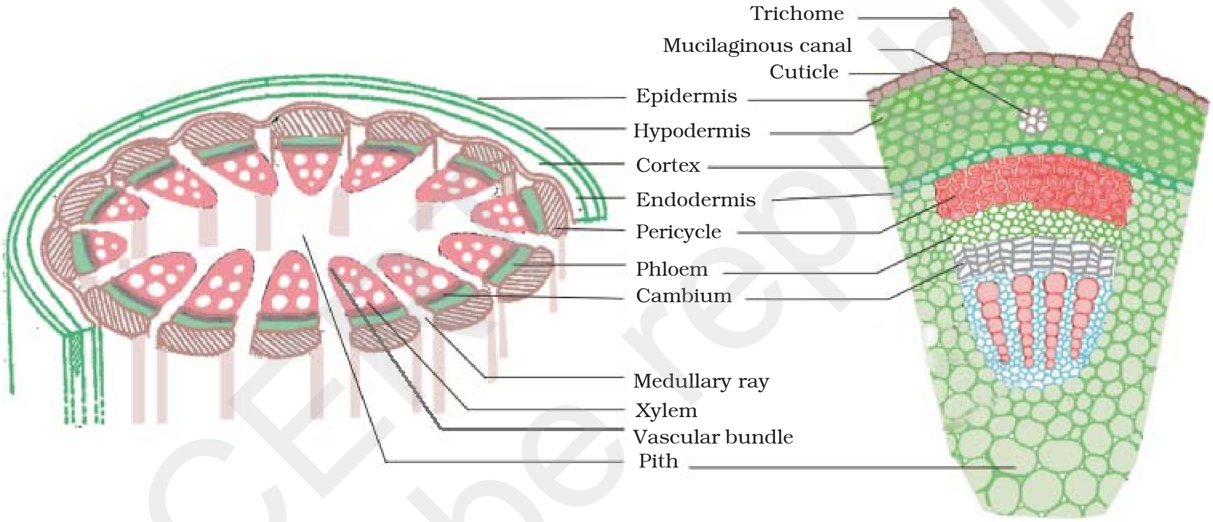


Fig. 6.3: *Section of a stem*

Activity 6.2

- Take a plant stem and with the help of your teacher cut into very thin slices or sections.
- Now, stain the slices with safranin. Place one neatly cut section on a slide, and put a drop of glycerine.
- Cover with a cover-slip and observe under a microscope. Observe the various types of cells and their arrangement. Compare it with Fig. 6.3.
- Now, answer the following on the basis of your observation:
  1. Are all cells similar in structure?
  2. How many types of cells can be seen?
  3. Can we think of reasons why there would be so many types of cells?
- We can also try to cut sections of plant roots. We can even try cutting sections of root and stem of different plants.

6.2.2 (i) Simple permanent tissue

A few layers of cells form the basic packing tissue. This tissue is parenchyma, a type of permanent tissue. It consists of relatively unspecialised cells with thin cell walls. They are live cells. They are usually loosely packed, so that large spaces between cells (intercellular spaces) are found in this tissue [Fig. 6.4 a(i)]. This tissue provides support to plants and also stores food. In some situations, it contains chlorophyll and performs photosynthesis, and then it is called chlorenchyma. In aquatic plants, large air cavities are present in parenchyma to give buoyancy to the plants to help them float. Such a parenchyma type is called aerenchyma. The parenchyma of stems and roots also stores nutrients and water.

The flexibility in plants is due to another permanent tissue, collenchyma. It allows easy bending in various parts of a plant (leaf, stem) without breaking. It also provides mechanical support to plants. We can find this tissue in leaf stalks below the epidermis. The cells of this tissue are living, elongated and irregularly thickened at the corners. There is very little intercellular space (Fig. 6.4 b).

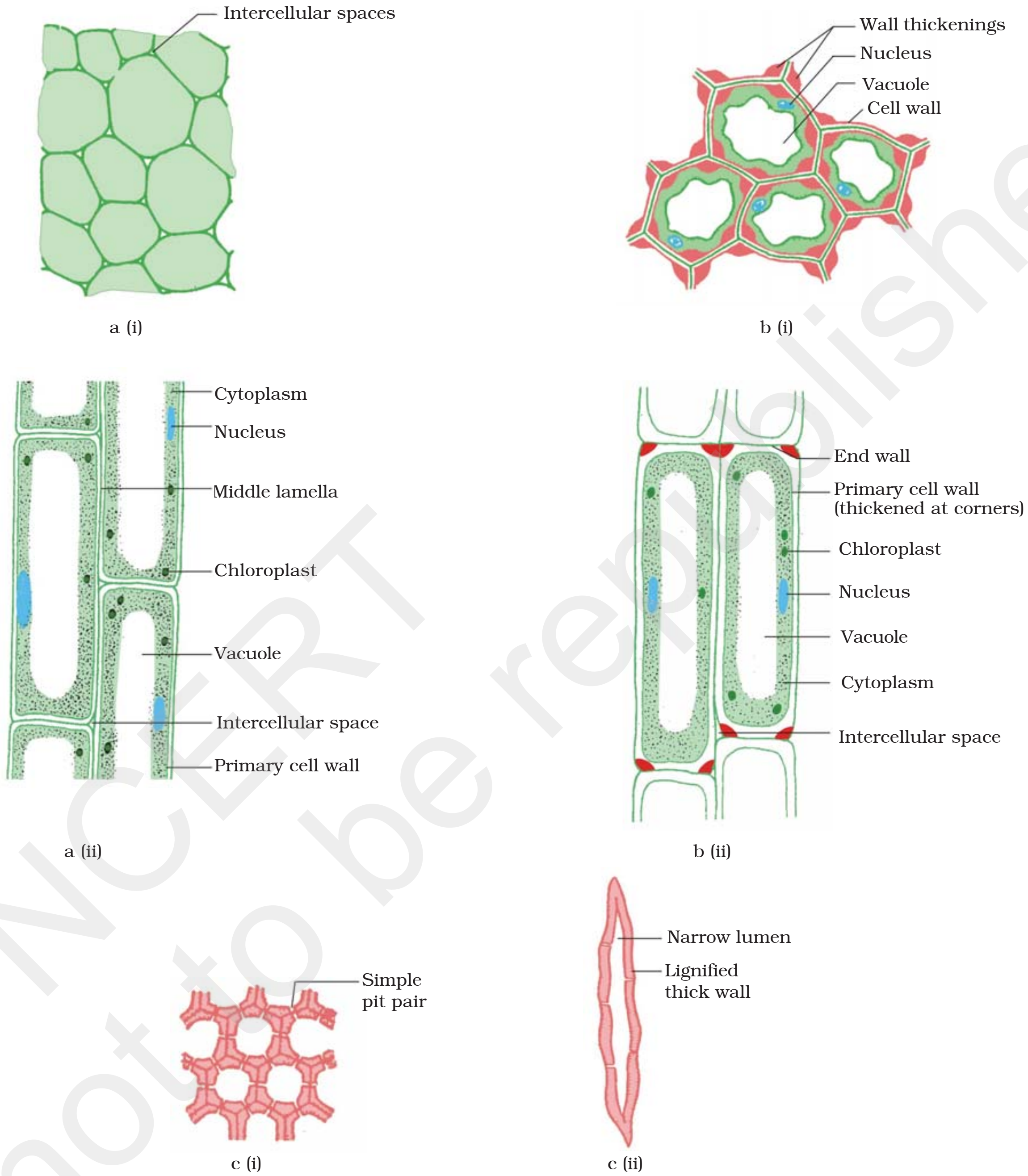


Fig. 6.4: *Various types of simple tissues: (a) Parenchyma (i) transverse section, (ii) longitudinal section; (b) Collenchyma (i) transverse section, (ii) longitudinal section; (c) Sclerenchyma (i) transverse section, (ii) longitudinal section.*

Yet another type of permanent tissue is sclerenchyma. It is the tissue which makes the plant hard and stiff. We have seen the husk of a coconut. It is made of sclerenchymatous tissue. The cells of this tissue are dead. They are long and narrow as the walls are thickened due to lignin (a chemical substance which acts as cement and hardens them). Often these walls are so thick that there is no internal space inside the cell (Fig. 6.4 c). This tissue is present in stems, around vascular bundles, in the veins of leaves and in the hard covering of seeds and nuts. It provides strength to the plant parts.

Activity 6.3

- Take a freshly plucked leaf of Rhoeo.
- Stretch and break it by applying pressure.
- While breaking it, keep it stretched gently so that some peel or skin projects out from the cut.
- Remove this peel and put it in a petri dish filled with water.
- Add a few drops of safranin.
- Wait for a couple of minutes and then transfer it onto a slide. Gently place a cover slip over it.
- Observe under microscope.

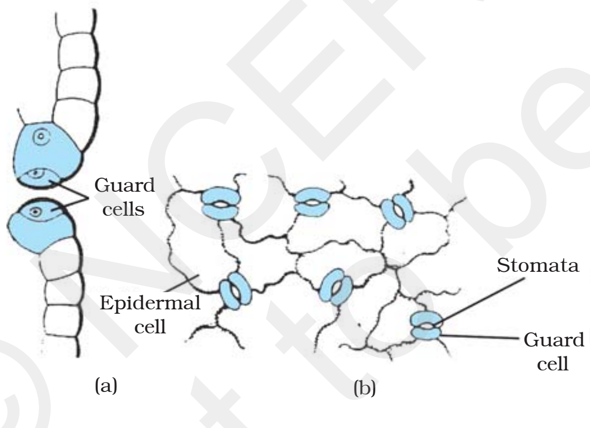


***Fig. 6.5:** Guard cells and epidermal cells: (a) lateral view, (b) surface view*

What you observe is the outermost layer of cells, called epidermis. The epidermis is usually made of a single layer of cells. In some plants living in very dry habitats, the epidermis may be thicker since protection against water loss is critical. The entire surface of a plant has this outer covering of epidermis. It protects all the parts of the plant. Epidermal cells on the aerial parts of the plant often secrete a waxy, water-resistant layer on their outer surface. This aids in protection against loss of water, mechanical injury and invasion by parasitic fungi. Since it has a protective role to play, cells of epidermal tissue form a continuous layer without intercellular spaces. Most epidermal cells are relatively flat. Often their outer and side walls are thicker than the inner wall.

We can observe small pores here and there in the epidermis of the leaf. These pores are called stomata (Fig. 6.5). Stomata are enclosed by two kidney-shaped cells called guard cells. They are necessary for exchanging gases with the atmosphere. Transpiration (loss of water in the form of water vapour) also takes place through stomata.

> Think about which gas may be required for photosynthesis.
> Find out the role of transpiration in plants.

Epidermal cells of the roots, whose function is water absorption, commonly bear long hair-like parts that greatly increase the total absorptive surface area.

In some plants like desert plants, epidermis has a thick waxy coating of cutin (chemical substance with waterproof quality) on its outer surface. Can we think of a reason for this?

Is the outer layer of a branch of a tree different from the outer layer of a young stem?

As plants grow older, the outer protective tissue undergoes certain changes. A strip of secondary meristem replaces the epidermis of the stem. Cells on the outside are cut off from this layer. This forms the several-layer thick cork or the bark of the tree. Cells of cork are dead and compactly arranged without intercellular spaces (Fig. 6.6). They also have a chemical called suberin in their walls that makes them impervious to gases and water.

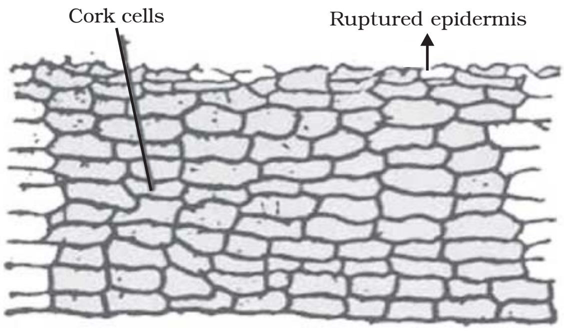


Fig. 6.6: *Protective tissue*

6.2.2 (ii) Complex permanent tissue

The different types of tissues we have discussed until now are all made of one type of cells, which look like each other. Such tissues are called simple permanent tissue. Yet another type of permanent tissue is complex tissue. Complex tissues are made of more than one type of cells. All these cells coordinate to perform a common function. Xylem and phloem are examples of such complex tissues. They are both conducting tissues and constitute a vascular bundle. Vascular or conductive tissue is a distinctive feature of the complex plants, one that has made possible their survival in the terrestrial environment. In Fig. 6.3 showing a section of stem, can you see different types of cells in the vascular bundle?

Xylem consists of tracheids, vessels, xylem parenchyma (Fig. 6.7 a,b,c) and xylem fibres. The cells have thick walls, and many of them are dead cells. Tracheids and vessels are tubular structures. This allows them to transport water and minerals vertically. The parenchyma stores food and helps in the sideways conduction of water. Fibres are mainly supportive in function.

Phloem is made up of four types of elements: sieve tubes, companion cells, phloem fibres and the phloem parenchyma [Fig. 6.7 (d)]. Sieve tubes are tubular cells with perforated walls. Phloem is unlike xylem in that materials can move in both directions in it. Phloem transports food from leaves to other parts of the plant. Except for phloem fibres, phloem cells are living cells.

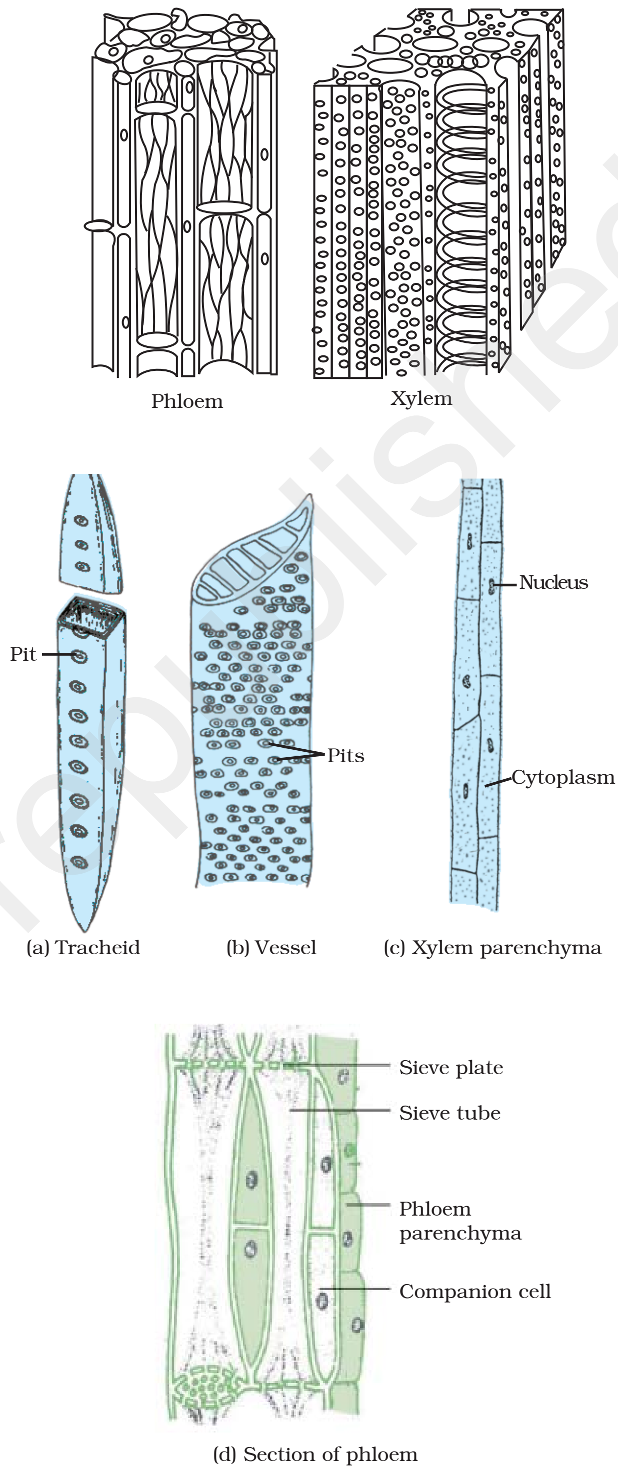


Fig. 6.7: *Types of complex tissue*

Questions

1. *Name types of simple tissues.*
2. *Where is apical meristem found?*
3. *Which tissue makes up the husk of coconut?*
4. *What are the constituents of phloem?*

6.3 Animal Tissues

When we breathe we can actually feel the movement of our chest. How do these body parts move? For this we have specialised cells called muscle cells (Fig. 6.8). The contraction and relaxation of these cells result in movement.

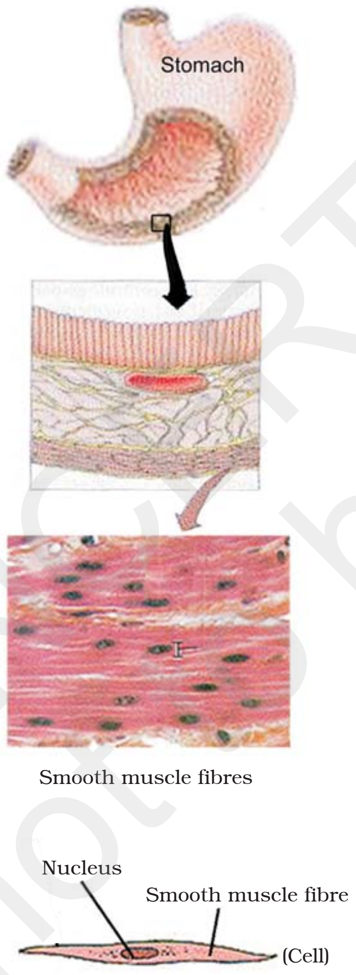


Fig. 6.8: *Location of muscle fibres*

During breathing we inhale oxygen. Where does this oxygen go? It is absorbed in the lungs and then is transported to all the body cells through blood. Why would cells need oxygen? The functions of mitochondria we studied earlier provide a clue to this question. Blood flows and carries various substances from one part of the body to the other. For example, it carries oxygen and food to all cells. It also collects wastes from all parts of the body and carries them to the liver and kidney for disposal.

Blood and muscles are both examples of tissues found in our body. On the basis of the functions they perform we can think of different types of animal tissues, such as epithelial tissue, connective tissue, muscular tissue and nervous tissue. Blood is a type of connective tissue, and muscle forms muscular tissue.

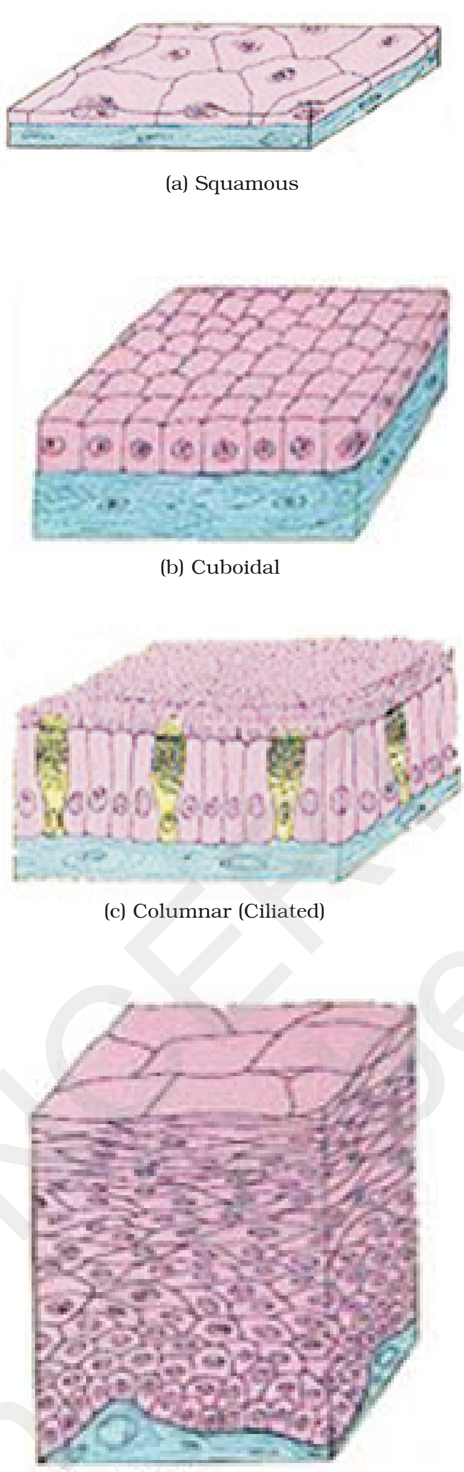
6.3.1 Epithelial Tissue

The covering or protective tissues in the animal body are epithelial tissues. Epithelium covers most organs and cavities within the body. It also forms a barrier to keep different body systems separate. The skin, the lining of the mouth, the lining of blood vessels, lung alveoli and kidney tubules are all made of epithelial tissue. Epithelial tissue cells are tightly packed and form a continuous sheet. They have only a small amount of cementing material between them and almost no intercellular spaces. Obviously, anything entering or leaving the body must cross at least one layer of epithelium. As a result, the permeability of the cells of various epithelia play an important role in regulating the exchange of materials between the body and the external environment and also between different parts of the body. Regardless of the type, all epithelium is usually separated from the underlying tissue by an extracellular fibrous basement membrane.

Different epithelia (Fig. 6.9) show differing structures that correlate with their unique functions. For example, in cells lining blood vessels or lung alveoli, where transportation of substances occurs through a selectively permeable surface, there is a simple flat kind of epithelium. This is called the simple squamous epithelium. Simple squamous epithelial cells are extremely thin and flat and form a delicate lining. The oesophagus and the lining of the mouth are also covered with squamous epithelium. The skin, which protects the body, is also made of squamous epithelium. Skin epithelial cells are arranged in many layers to prevent wear and tear. Since they are arranged in a pattern of layers, the epithelium is called stratified squamous epithelium.

Where absorption and secretion occur, as in the inner lining of the intestine, tall epithelial cells are present. This columnar (meaning 'pillar-like') epithelium facilitates movement across the epithelial barrier. In the respiratory tract, the columnar epithelial tissue also has cilia, which are hair-like projections on the outer surfaces of epithelial cells. These cilia can move, and their movement pushes the mucus forward to clear it. This type of epithelium is thus ciliated columnar epithelium.

Cuboidal epithelium (with cube-shaped cells) forms the lining of kidney tubules and ducts of salivary glands, where it provides mechanical support. Epithelial cells often acquire additional specialisation as gland cells, which can secrete substances at the epithelial surface. Sometimes a portion of the epithelial tissue folds inward, and a multicellular gland is formed. This is glandular epithelium.



(a) Squamous

(b) Cuboidal

(c) Columnar (Ciliated)

(d) Stratified squamous

Fig. 6.9: *Different types of epithelial tissues*

6.3.2 Connective tissue

Blood is a type of connective tissue. Why would it be called 'connective' tissue? A clue is provided in the introduction of this chapter! Now, let us look at this type of tissue in some more detail. The cells of connective tissue are loosely spaced and embedded in an intercellular matrix (Fig. 6.10). The matrix may be jelly like, fluid, dense or rigid. The nature of matrix differs in concordance with the function of the particular connective tissue.

Take a drop of blood on a slide and observe different cells present in it under a microscope.

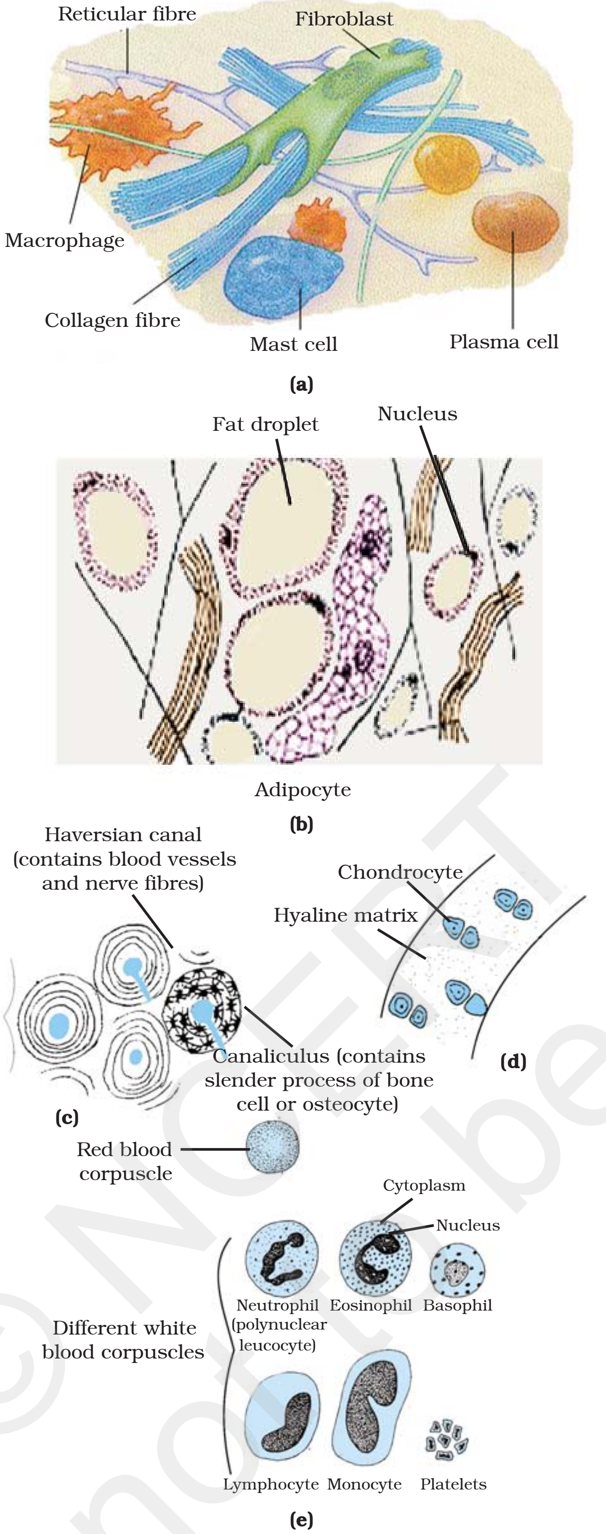


Fig. 6.10: *Types of connective tissues: (a) areolar tissue, (b) adipose tissue, (c) compact bone, (d) hyaline cartilage, (e) types of blood cells*

Blood has a fluid (liquid) matrix called plasma, in which red blood cells (RBCs), white blood cells (WBCs) and platelets are suspended. The plasma contains proteins, salts and hormones. Blood flows and transports gases, digested food, hormones and waste materials to different parts of the body.

Bone is another example of a connective tissue. It forms the framework that supports the body. It also anchors the muscles and supports the main organs of the body. It is a strong and nonflexible tissue (what would be the advantage of these properties for bone functions?). Bone cells are embedded in a hard matrix that is composed of calcium and phosphorus compounds.

Two bones can be connected to each other by another type of connective tissue called the ligament. This tissue is very elastic. It has considerable strength. Ligaments contain very little matrix. Tendons connect muscles to bones and are another type of connective tissue. Tendons are fibrous tissue with great strength but limited flexibility.

Another type of connective tissue, cartilage, has widely spaced cells. The solid matrix is composed of proteins and sugars. Cartilage smoothens bone surfaces at joints and is also present in the nose, ear, trachea and larynx. We can fold the cartilage of the ears, but we cannot bend the bones in our arms. Think of how the two tissues are different!

Areolar connective tissue is found between the skin and muscles, around blood vessels and nerves and in the bone marrow. It fills the space inside the organs, supports internal organs and helps in repair of tissues.

Where are fats stored in our body? Fat-storing adipose tissue is found below the skin and between internal organs. The cells of this tissue are filled with fat globules. Storage of fats also lets it act as an insulator.

6.3.3 MUSCULAR TISSUE

Muscular tissue consists of elongated cells, also called muscle fibres. This tissue is responsible for movement in our body.

Muscles contain special proteins called contractile proteins, which contract and relax to cause movement.

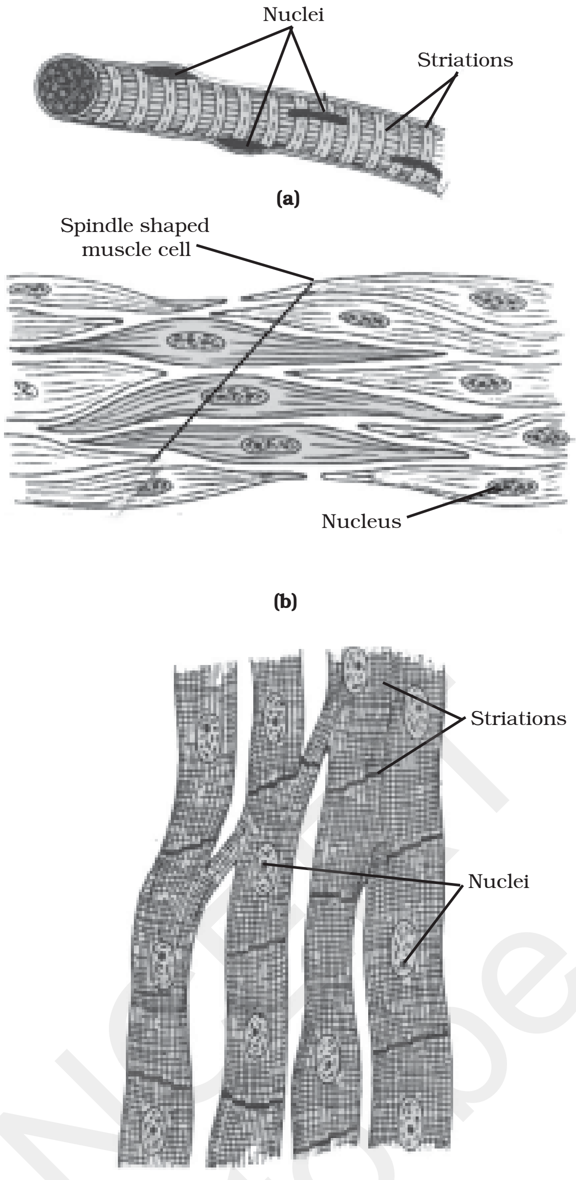


Fig. 6.11: *Types of muscles fibres: (a) striated muscle, (b) smooth muscle, (c) cardiac muscle*

We can move some muscles by conscious will. Muscles present in our limbs move when we want them to, and stop when we so decide. Such muscles are called voluntary muscles [Fig. 6.11(a)]. These muscles are also called skeletal muscles as they are mostly attached to bones and help in body movement. Under the microscope, these muscles show alternate light and dark bands or striations when stained appropriately. As a result, they are also called striated muscles. The cells of this tissue are long, cylindrical, unbranched and multinucleate (having many nuclei).

The movement of food in the alimentary canal or the contraction and relaxation of blood vessels are involuntary movements. We cannot really start them or stop them simply by wanting to do so! Smooth muscles [Fig. 6.11(b)] or involuntary muscles control such movements. They are also found in the iris of the eye, in ureters and in the bronchi of the lungs. The cells are long with pointed ends (spindle-shaped) and uninucleate (having a single nucleus). They are also called unstriated muscles – why would they be called that?

The muscles of the heart show rhythmic contraction and relaxation throughout life. These involuntary muscles are called cardiac muscles [Fig. 6.11(c)]. Heart muscle cells are cylindrical, branched and uninucleate.

Compare the structures of different types of muscular tissues. Note their shape, number of nuclei and position of nuclei within the cell.

6.3.4 Nervous tissue

All cells possess the ability to respond to stimuli. However, cells of the nervous tissue are highly specialised for being stimulated and then transmitting the stimulus very rapidly from one place to another within the body. The brain, spinal cord and nerves are all composed of the nervous tissue. The cells of this tissue are called nerve cells or neurons. A neuron consists of a cell body with a nucleus and cytoplasm, from which long thin hair-like parts arise (Fig. 6.12). Usually each neuron has a single long part, called the axon, and many short, branched parts called dendrites. An individual nerve cell may be up to a metre long. Many nerve fibres bound together by connective tissue make up a nerve.

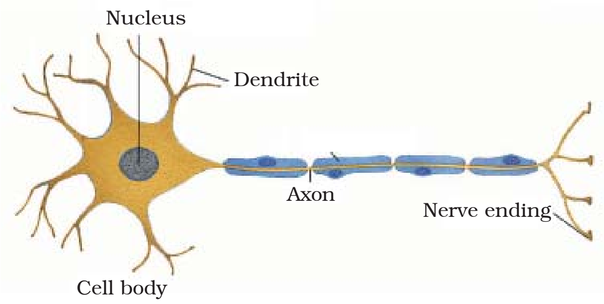


Fig. 6.12: *Neuron-unit of nervous tissue*

Nerve impulses allow us to move our muscles when we want to. The functional combination of nerve and muscle tissue is fundamental to most animals. This combination enables animals to move rapidly in response to stimuli.

Questions

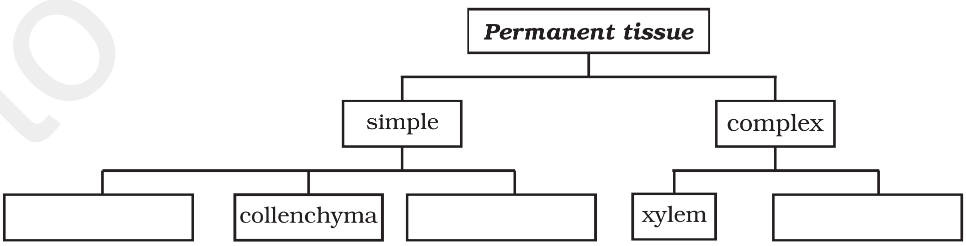
1. *Name the tissue responsible for movement in our body.*
2. *What does a neuron look like?*
3. *Give three features of cardiac muscles.*
4. *What are the functions of areolar tissue?*

What you have learnt

- Tissue is a group of cells similar in structure and function.
- Plant tissues are of two main types – meristematic and permanent.
- Meristematic tissue is the dividing tissue present in the growing regions of the plant.
- Permanent tissues are derived from meristematic tissue once they lose the ability to divide. They are classified as simple and complex tissues.
- Parenchyma, collenchyma and sclerenchyma are three types of simple tissues. Xylem and phloem are types of complex tissues.
- Animal tissues can be epithelial, connective, muscular and nervous tissue.
- Depending on shape and function, epithelial tissue is classified as squamous, cuboidal, columnar, ciliated and glandular.
- The different types of connective tissues in our body include areolar tissue, adipose tissue, bone, tendon, ligament, cartilage and blood.
- Striated, unstriated and cardiac are three types of muscle tissues.
- Nervous tissue is made of neurons that receive and conduct impulses.

Exercises

1. Define the term “tissue”.
2. How many types of elements together make up the xylem tissue? Name them.
3. How are simple tissues different from complex tissues in plants?
4. Differentiate between parenchyma, collenchyma and sclerenchyma on the basis of their cell wall.
5. What are the functions of the stomata?
6. Diagrammatically show the difference between the three types of muscle fibres.
7. What is the specific function of the cardiac muscle?
8. Differentiate between striated, unstriated and cardiac muscles on the basis of their structure and site/location in the body.
9. Draw a labelled diagram of a neuron.
10. Name the following.
    (a) Tissue that forms the inner lining of our mouth.
    (b) Tissue that connects muscle to bone in humans.
    (c) Tissue that transports food in plants.
    (d) Tissue that stores fat in our body.
    (e) Connective tissue with a fluid matrix.
    (f) Tissue present in the brain.
11. Identify the type of tissue in the following: skin, bark of tree, bone, lining of kidney tubule, vascular bundle.
12. Name the regions in which parenchyma tissue is present.
13. What is the role of epidermis in plants?
14. How does the cork act as a protective tissue?
15. Complete the table:



Chapter 7

DIVERSITY IN LIVING ORGANISMS

Have you ever thought of the multitude of life-forms that surround us? Each organism is different from all others to a lesser or greater extent. For instance, consider yourself and a friend.

- Are you both of the same height?
- Does your nose look exactly like your friend's nose?
- Is your hand-span the same as your friend's?

However, if we were to compare ourselves and our friends with a monkey, what would we say? Obviously, we and our friends have a lot in common when we compare ourselves with a monkey. But suppose we were to add a cow to the comparison? We would then think that the monkey has a lot more in common with us than with the cow.

Activity 7.1

- We have heard of '*desi* cows and Jersey cows.
- Does a *desi* cow look like a Jersey cow?
- Do all *desi* cows look alike?
- Will we be able to identify a Jersey cow in a crowd of *desi* cows that don't look like each other?
- What is the basis of our identification?

In this activity, we had to decide which characteristics were more important in forming the desired category. Hence, we were also deciding which characteristics could be ignored.

Now, think of all the different forms in which life occurs on earth. On one hand we have microscopic bacteria of a few micrometre in size. While on the other hand we have blue whale and red wood trees of california of approximate sizes of 30 metres and 100 metres respectively. Some pine trees live for thousands of years while insects like mosquitoes die within a few days. Life also ranges from colourless or even transparent worms to brightly coloured birds and flowers.

This bewildering variety of life around us has evolved on the earth over millions of years. However, we do not have more than a tiny fraction of this time to try and understand all these living organisms, so we cannot look at them one by one. Instead, we look for similarities among the organisms, which will allow us to put them into different classes and then study different classes or groups as a whole.

In order to make relevant groups to study the variety of life forms, we need to decide which characteristics decide more fundamental differences among organisms. This would create the main broad groups of organisms. Within these groups, smaller sub-groups will be decided by less important characteristics.

Questions

1. *Why do we classify organisms?*
2. *Give three examples of the range of variations that you see in life-forms around you.*

7.1 What is the Basis of Classification?

Attempts at classifying living things into groups have been made since time immemorial. Greek thinker Aristotle classified animals according to whether they lived on land, in water or in the air. This is a very simple way of looking at life, but misleading too. For example, animals that live in the sea include corals, whales, octopuses, starfish and sharks. We can immediately see that these are very different from each other in numerous ways. In fact, their habitat is the only point they share in common. This is not an appropriate way of making groups of organisms to study and think about.

We therefore need to decide which characteristics to be used as the basis for making the broadest divisions. Then we will have to pick the next set of characteristics for making sub-groups within these divisions. This process of classification within each group can then continue using new characteristics each time.

Before we go on, we need to think about what is meant by 'characteristics'. When we are trying to classify a diverse group of organisms, we need to find ways in which some of them are similar enough to be thought of together. These 'ways', in fact, are details of appearance or behaviour, in other words, form and function.

What we mean by a characteristic is a particular form or a particular function. That most of us have five fingers on each hand is thus a characteristic. That we can run, but the banyan tree cannot, is also a characteristic.

Now, to understand how some characteristics are decided as being more fundamental than others, let us consider how a stone wall is built. The stones used will have different shapes and sizes. The stones at the top of the wall would not influence the choice of stones that come below them. On the other hand, the shapes and sizes of stones in the lowermost layer will decide the shape and size of the next layer and so on.

The stones in the lowermost layer are like the characteristics that decide the broadest divisions among living organisms. They are independent of any other characteristics in their effects on the form and function of the organism. The characteristics in the next level would be dependent on the previous one and would decide the variety in the next level. In this way, we can build up a whole hierarchy of mutually related characteristics to be used for classification.

Now-a-days, we look at many inter-related characteristics starting from the nature of the cell in order to classify all living organisms. What are some concrete examples of such characteristics used for a hierarchical classification?

- A eukaryotic cell has membrane-bound organelles, including a nucleus, which allow cellular processes to be carried out efficiently in isolation from each other. Therefore, organisms which do not have a clearly demarcated nucleus and other organelles would need to have their biochemical pathways organised in very different ways. This would have an effect on every aspect of cell design. Further, nucleated cells would have the capacity to participate in making a multicellular organism because they can take up specialised functions. Therefore, this is a basic characteristic of classification.
- Do the cells occur singly or are they grouped together and do they live as an indivisible group? Cells that group together to form a single organism use the principle of division of labour. In such a body design, all cells would not be identical. Instead, groups of cells will carry out specialised functions. This makes a very basic distinction in the body designs of organisms. As a result, an Amoeba and a worm are very different in their body design.
- Do organisms produce their own food through the process of photosynthesis? Being able to produce one's own food versus having to get food from outside would make very different body designs necessary.
- Of the organisms that perform photosynthesis (plants), what is the level of organisation of their body?
- Of the animals, how does the individual's body develop and organise its different parts, and what are the specialised organs found for different functions?

We can see that, even in these few questions that we have asked, a hierarchy is developing. The characteristics of body design used for classification of plants will be very different from those important for classifying animals. This is because the basic designs are different, based on the need to make their own food (plants), or acquire it (animals). Therefore, these design features (having a skeleton, for example) are to be used to make sub-groups, rather than making broad groups.

Questions

1. *Which do you think is a more basic characteristic for classifying organisms?*
   (a) the place where they live.
   (b) the kind of cells they are made of. Why?
2. *What is the primary characteristic on which the first division of organisms is made?*
3. *On what bases are plants and animals put into different categories?*

7.2 Classification and Evolution

All living things are identified and categorised on the basis of their body design in form and function. Some characteristics are likely to make more wide-ranging changes in body design than others. There is a role of time in this as well. So, once a certain body design comes into existence, it will shape the effects of all other subsequent design changes, simply because it already exists. In other words, characteristics that came into existence earlier are likely to be more basic than characteristics that have come into existence later.

This means that the classification of life forms will be closely related to their evolution. What is evolution? Most life forms that we see today have arisen by an accumulation of changes in body design that allow the organism possessing them to survive better. Charles Darwin first described this idea of evolution in 1859 in his book, *The Origin of Species*.

When we connect this idea of evolution to classification, we will find some groups of organisms which have ancient body designs that have not changed very much. We will also find other groups of organisms that have acquired their particular body designs relatively recently. Those in the first group are frequently referred to as 'primitive' or 'lower' organisms, while those in the second group are called 'advanced' or 'higher' organisms. In reality, these terms are not quite correct since they do not properly relate to the differences. All that we can say is that some are 'older' organisms, while some are 'younger' organisms. Since there is a possibility that complexity in design will increase over evolutionary time, it may not be wrong to say that older organisms are simpler, while younger organisms are more complex.

More to know

Biodiversity means the diversity of life forms. It is a word commonly used to refer to the variety of life forms found in a particular region. Diverse life forms share the environment, and are affected by each other too. As a result, a stable community of different species comes into existence. Humans have played their own part in recent times in changing the balance of such communities. Of course, the diversity in such communities is affected by particular characteristics of land, water, climate and so on. Rough estimates state that there are about ten million species on the planet, although we actually know only one or two millions of them. The warm and humid tropical regions of the earth, between the tropic of Cancer and the tropic of Capricorn, are rich in diversity of plant and animal life. This is called the region of megadiversity. Of the biodiversity of the planet, more than half is concentrated in a few countries – Brazil, Colombia, Ecuador, Peru, Mexico, Zaire, Madagascar, Australia, China, India, Indonesia and Malaysia.

Questions

1. *Which organisms are called primitive and how are they different from the so-called advanced organisms?*
2. *Will advanced organisms be the same as complex organisms? Why?*

7.3 The Hierarchy of Classification-Groups

Biologists, such as Ernst Haeckel (1894), Robert Whittaker (1959) and Carl Woese (1977) have tried to classify all living organisms into broad categories, called kingdoms. The classification Whittaker proposed has five kingdoms: Monera, Protista, Fungi, Plantae and Animalia, and is widely used. These groups are formed on the basis of their cell structure, mode and source of nutrition and body organisation. The modification Woese introduced by dividing the Monera into Archaebacteria (or Archaea) and Eubacteria (or Bacteria) is also in use.

Further classification is done by naming the sub-groups at various levels as given in the following scheme:

Kingdom
Phylum (for animals) / Division (for plants)
Class
Order
Family
Genus
Species

Thus, by separating organisms on the basis of a hierarchy of characteristics into smaller and smaller groups, we arrive at the basic unit of classification, which is a 'species'. So what organisms can be said to belong to the same species? Broadly, a species includes all organisms that are similar enough to breed and perpetuate.

The important characteristics of the five kingdoms of Whittaker are as follows:

7.3.1 Monera

These organisms do not have a defined nucleus or organelles, nor do any of them show multi-cellular body designs. On the other hand, they show diversity based on many other characteristics. Some of them have cell walls while some do not. Of course, having or not having a cell wall has very different effects on body design here from having or not having a cell wall in multi-cellular organisms. The mode of nutrition of organisms in this group can be either by synthesising their own food (autotrophic) or getting it from the environment (heterotrophic). This group includes bacteria, blue-green algae or cyanobacteria, and mycoplasma. Some examples are shown in Fig. 7.1.

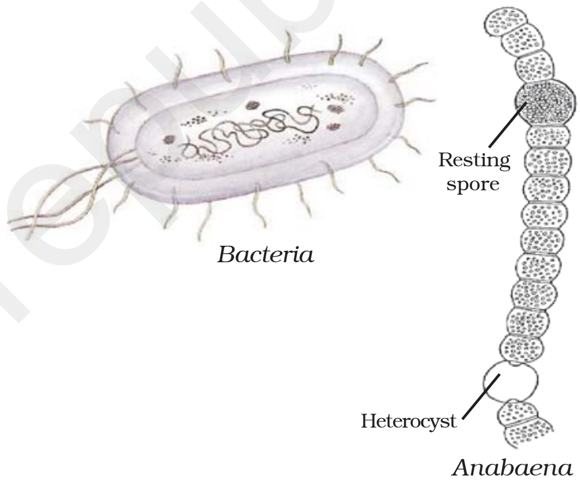
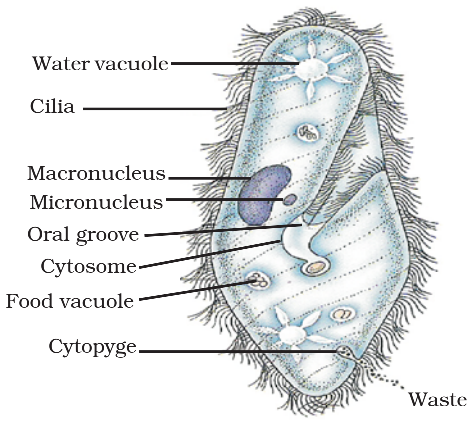


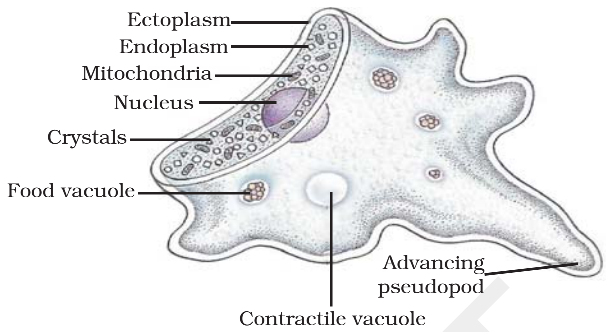
Fig. 7.1: Monera

7.3.2 Protista

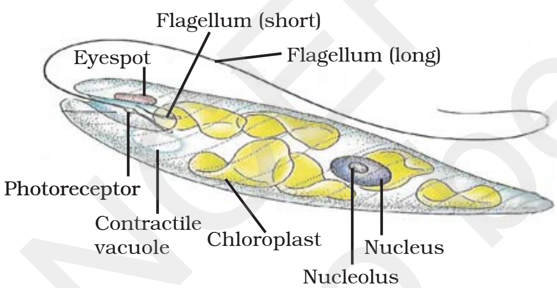
This group includes many kinds of unicellular eukaryotic organisms. Some of these organisms use appendages, such as hair-like cilia or whip-like flagella for moving around. Their mode of nutrition can be autotrophic or heterotrophic. Examples are unicellular algae, diatoms and protozoans (see Fig. 7.2 for examples).



Paramecium



Amoeba



Euglena

Fig. 7.2: *Protozoa*

7.3.3 Fungi

These are heterotrophic eukaryotic organisms. They use decaying organic material as food and are therefore called saprophytes. Many of them have the capacity to become multicellular organisms at certain stages in their lives. They have cell-walls made of a tough complex sugar called chitin. Examples are yeast and mushrooms (see Fig. 7.3 for examples).

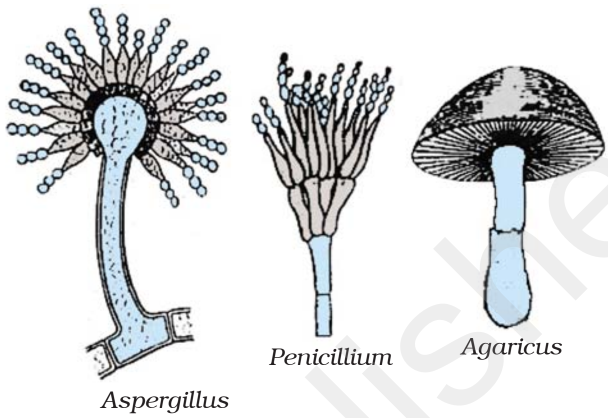


Fig. 7.3: Fungi

Some fungal species live in permanent mutually dependent relationships with blue-green algae (or cyanobacteria). Such relationships are called symbiotic. These symbiobic life forms are called lichens. We have all seen lichens as the slow-growing large coloured patches on the bark of trees.

7.3.4 Plantae

These are multicellular eukaryotes with cell walls. They are autotrophs and use chlorophyll for photosynthesis. Thus, all plants are included in this group. Since plants and animals are most visible forms of the diversity of life around us, we will look at the subgroups in this category later (section 7.4).

7.3.5 Animalia

These include all organisms which are multicellular eukaryotes without cell walls. They are heterotrophs. Again, we will look at their subgroups a little later in section 7.5.

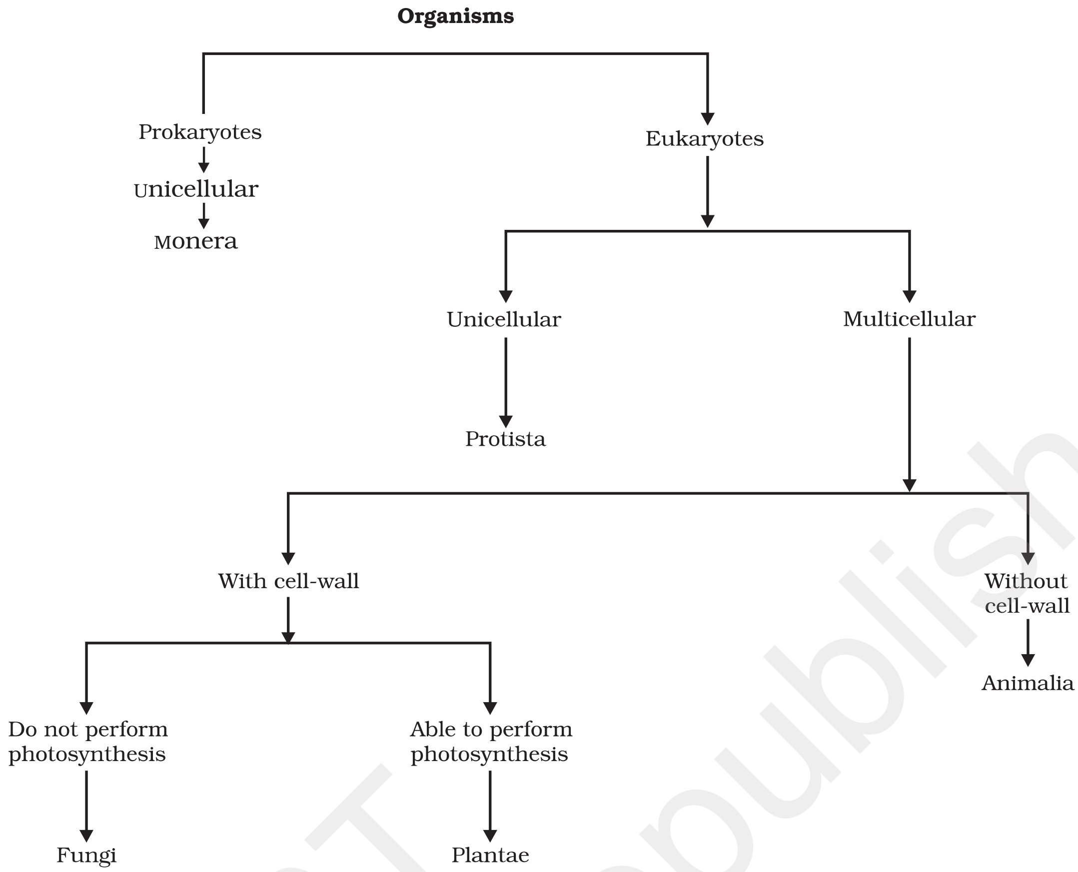


Fig. 7.4: *The Five Kingdom classification*

Questions

1. *What is the criterion for classification of organisms as belonging to kingdom Monera or Protista?*
2. *In which kingdom will you place an organism which is single-celled, eukaryotic and photosynthetic?*
3. *In the hierarchy of classification, which grouping will have the smallest number of organisms with a maximum of characteristics in common and which will have the largest number of organisms?*

7.4 Plantae

The first level of classification among plants depends on whether the plant body has well-differentiated, distinct components. The next level of classification is based on whether the differentiated plant body has special tissues for the transport of water and other substances within it. Further classification looks at the ability to bear seeds and whether the seeds are enclosed within fruits.

7.4.1 THALLOPHYTA

Plants that do not have well-differentiated body design fall in this group. The plants in this group are commonly called algae. These plants are predominantly aquatic. Examples are *Spirogyra*, *Ulothrix*, *Cladophora* and *Chara* (see Fig. 7.5).

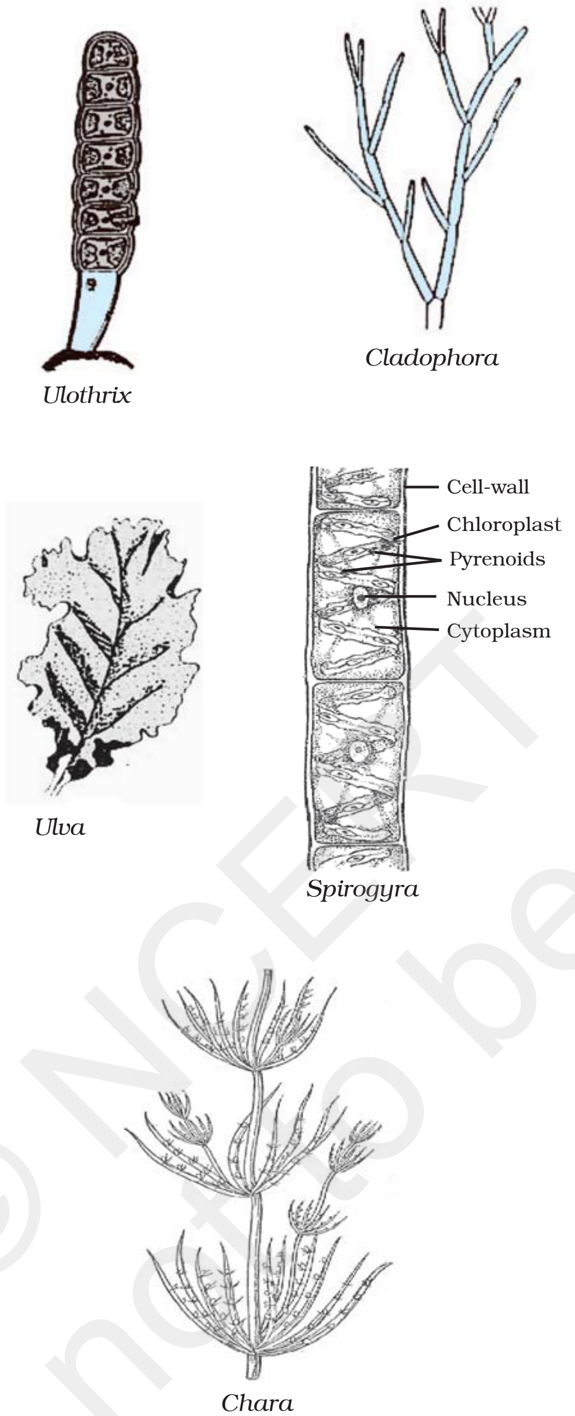


Fig. 7.5: *Thallophyta – Algae*

7.4.2 Bryophyta

These are called the amphibians of the plant kingdom. The plant body is commonly differentiated to form stem and leaf-like structures. However, there is no specialised tissue for the conduction of water and other substances from one part of the plant body to another. Examples are moss (*Funaria*) and *Marchantia* (see Fig. 7.6).

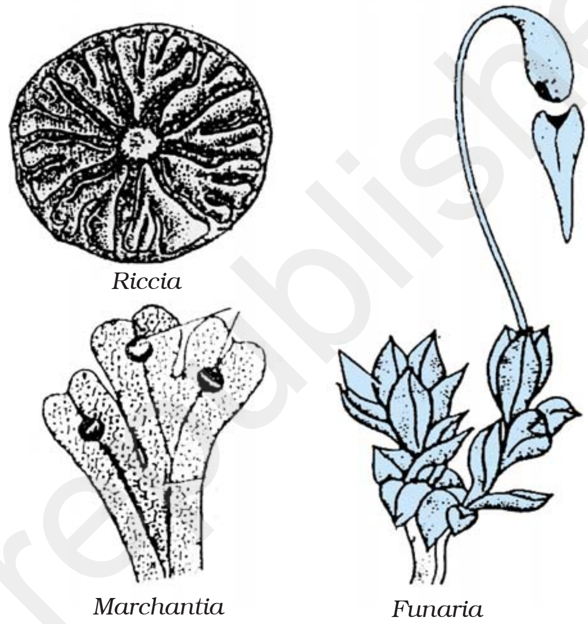


Fig. 7.6: *Some common bryophytes*

7.4.3 Pteridophyta

In this group, the plant body is differentiated into roots, stem and leaves and has specialised tissue for the conduction of water and other substances from one part of the plant body to another. Some examples are *Marsilea*, ferns and horse-tails (see Fig. 7.7).

The thallophytes, the bryophytes and the pteridophytes have naked embryos that are called spores. The reproductive organs of plants in all these three groups are very inconspicuous, and they are therefore called 'cryptogamae', or 'those with hidden reproductive organs'.

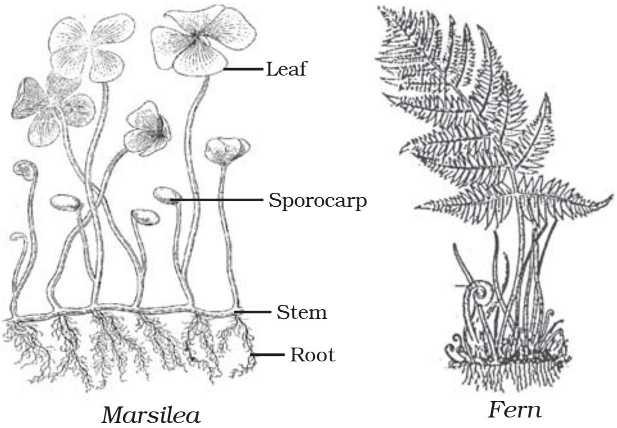


Fig. 7.7: *Pteridophyta*

On the other hand, plants with well-differentiated reproductive tissues that ultimately make seeds are called phanerogams. Seeds are the result of the reproductive process. They consist of the embryo along with stored food, which serves for the initial growth of the embryo during germination. This group is further classified, based on whether the seeds are naked or enclosed in fruits, giving us two groups: gymnosperms and angiosperms.

7.4.4 Gymnosperms

This term is made from two Greek words: *gymno*– means naked and *sperma*– means seed. The plants of this group bear naked seeds and are usually perennial, evergreen and woody. Examples are pines and deodar (see Fig. 7.8 for examples).

Fig. 7.8: *Gymnosperms*

7.4.5 Angiosperms

This word is made from two Greek words: *angio* means covered and *sperma*– means seed. The seeds develop inside an organ which is modified to become a fruit. These are also called flowering plants. Plant embryos in seeds have structures called cotyledons. Cotyledons are called 'seed leaves' because in many instances they emerge and become green when the seed germinates. Thus, cotyledons represent a bit of pre-designed plant in the seed. The angiosperms are divided into two groups on the basis of the number of cotyledons present in the seed. Plants with seeds having a single cotyledon are called monocotyledonous or monocots. Plants with seeds having two cotyledons are called dicots (see Figs. 7.9 and 7.10).

Fig. 7.9: *Monocots – Paphiopedilum*

Fig. 7.10: *Dicots – Ipomoea*

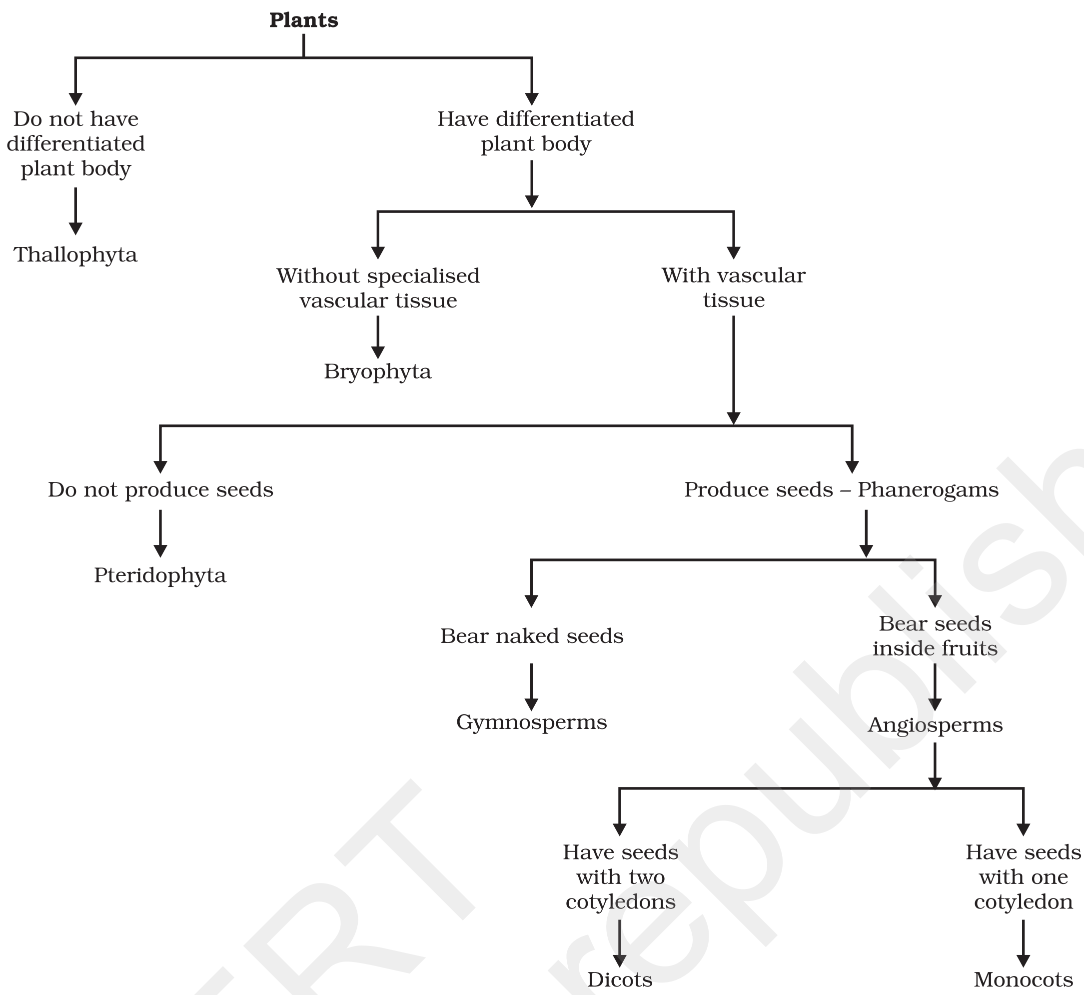


Fig. 7.11: *Classification of plants*

Activity 7.2

- Soak seeds of green gram, wheat, maize, peas and tamarind. Once they become tender, try to split the seed. Do all the seeds break into two nearly equal halves?
- The seeds that do are the dicot seeds and the seeds that don't are the monocot seeds.
- Now take a look at the roots, leaves and flowers of these plants.
- Are the roots tap-roots or fibrous?
- Do the leaves have parallel or reticulate venation?
- How many petals are found in the flower of these plants?
- Can you write down further characteristics of monocots and dicots on the basis of these observations?

Questions

1. *Which division among plants has the simplest organisms?*
2. *How are pteridophytes different from the phanerogams?*
3. *How do gymnosperms and angiosperms differ from each other?*

7.5 Animalia

These are organisms which are eukaryotic, multicellular and heterotrophic. Their cells do not have cell-walls. Most animals are mobile.

They are further classified based on the extent and type of the body design differentiation found.

7.5.1 Porifera

The word Porifera means organisms with holes. These are non-motile animals attached to some solid support. There are holes or 'pores', all over the body. These lead to a canal system that helps in circulating water throughout the body to bring in food and oxygen. These animals are covered with a hard outside layer or skeleton. The body design involves very minimal differentiation and division into tissues. They are commonly called sponges, and are mainly found in marine habitats. Some examples are shown in Fig. 7.12.

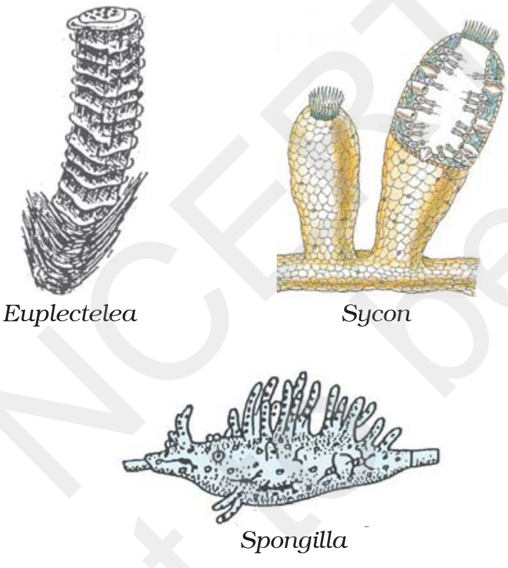


Fig. 7.12: *Porifera*

7.5.2 Coelenterata (Cnidaria)

These are animals living in water. They show more body design differentiation. There is a cavity in the body. The body is made of two layers of cells: one makes up cells on the outside of the body, and the other makes the inner lining of the body. Some of these species live in colonies (corals), while others have a solitary like–span (*Hydra*). Jellyfish and sea anemones are common examples (see Fig. 7.13).

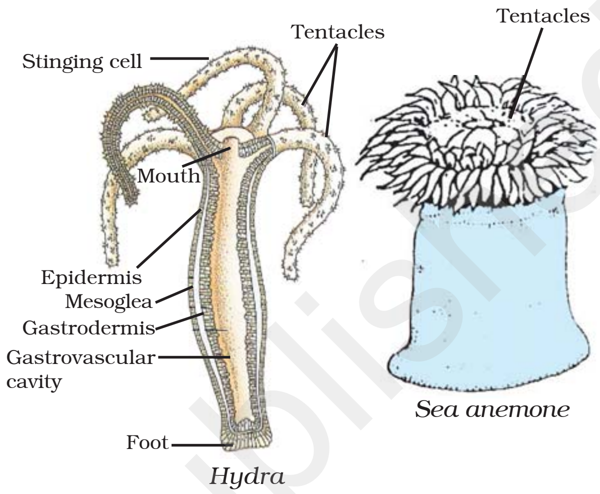


Fig. 7.13: *Coelenterata*

7.5.3 Platyhelminthes

The body of animals in this group is far more complexly designed than in the two other groups we have considered so far. The body is bilaterally symmetrical, meaning that the left and the right halves of the body have the same design. There are three layers of cells from which differentiated tissues can be made, which is why such animals are called triploblastic. This allows outside and inside body linings as well as some organs to be made. There is thus some degree of tissue formation. However, there is no true internal body cavity or coelom, in which well-developed organs can be accommodated. The body is flattened dorsiventrally, meaning from top to bottom, which is why these animals are called flatworms. They are either free-living or parasitic. Some examples are free-living animals like planarians, or parasitic animals like liverflukes (see Fig. 7.14 for examples).

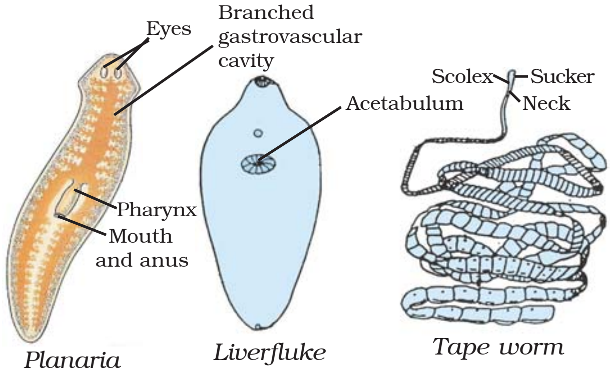


Fig. 7.14: *Platyhelminthes*

7.5.4 Nematoda

The nematode body is also bilaterally symmetrical and triploblastic. However, the body is cylindrical rather than flattened. There are tissues, but no real organs, although a sort of body cavity or a pseudo-coelom, is present. These are very familiar as parasitic worms causing diseases, such as the worms causing elephantiasis (filarial worms) or the worms in the intestines (roundworm or pinworms). Some examples are shown in Fig. 7.15.

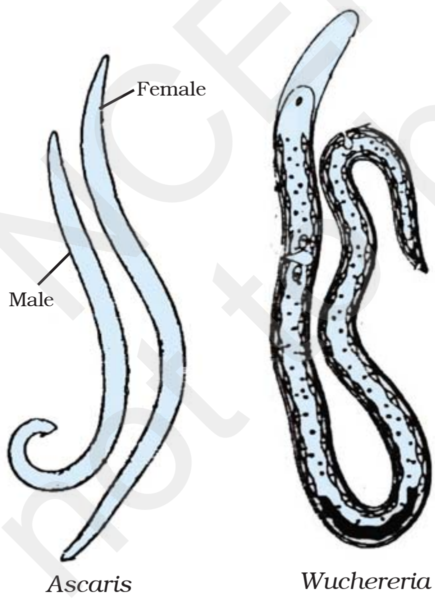


Fig. 7.15: *Nematodes (Aschelminthes)*

7.5.5 Annelida

Annelid animals are also bilaterally symmetrical and triploblastic, but in addition they have a true body cavity. This allows true organs to be packaged in the body structure. There is, thus, extensive organ differentiation. This differentiation occurs in a segmental fashion, with the segments lined up one after the other from head to tail. These animals are found in a variety of habitats– fresh water, marine water as well as land. Earthworms and leeches are familiar examples (see Fig. 7.16).

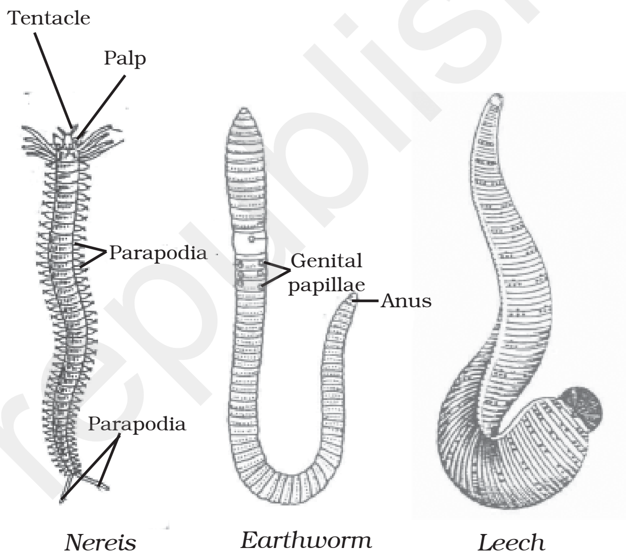


Fig. 7.16: *Annelida*

7.5.6 Arthropoda

This is probably the largest group of animals. These animals are bilaterally symmetrical and segmented. There is an open circulatory system, and so the blood does not flow in well-defined blood vessels. The coelomic cavity is blood-filled. They have jointed legs (the word 'arthropod' means 'jointed legs'). Some familiar examples are prawns, butterflies, houseflies, spiders, scorpions and crabs (see Fig. 7.17).

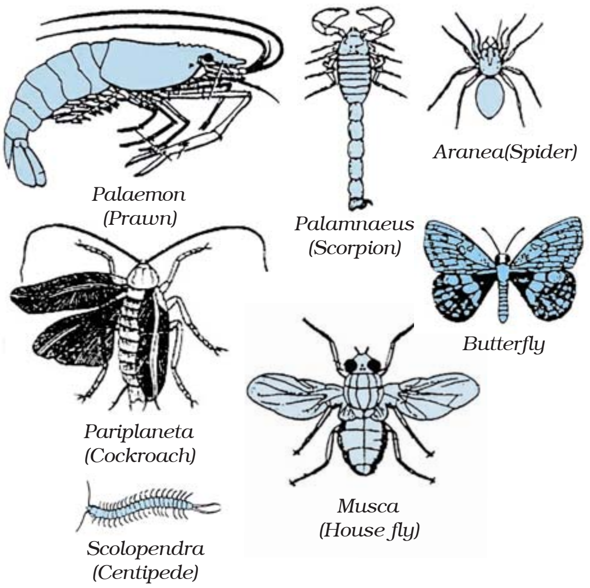


Fig. 7.17: *Arthropoda*

7.5.7 Mollusca

In the animals of this group, there is bilateral symmetry. The coelomic cavity is reduced. There is little segmentation. They have an open circulatory system and kidney-like organs for excretion. There is a foot that is used for moving around. Examples are snails and mussels (see Fig. 7.18).

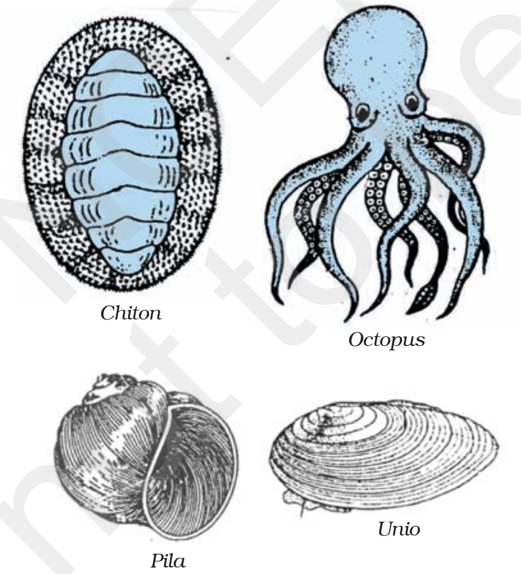


Fig. 7.18: *Mollusca*

7.5.8 Echinodermata

In Greek, *echinos* means hedgehog, and *derma* means skin. Thus, these are spiny skinned organisms. These are exclusively free-living marine animals. They are triploblastic and have a coelomic cavity. They also have a peculiar water-driven tube system that they use for moving around. They have hard calcium carbonate structures that they use as a skeleton. Examples are starfish and sea urchins (see Fig. 7.19).

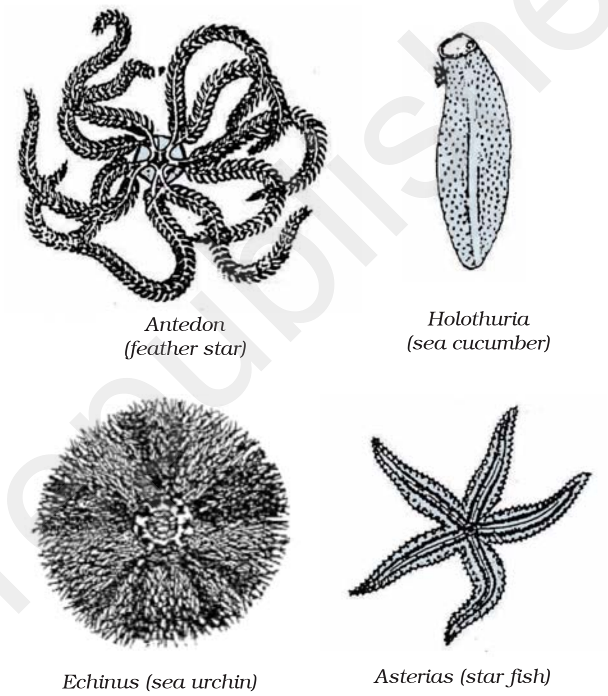


Fig. 7.19: *Echinodermata*

7.5.9 Protochordata

These animals are bilaterally symmetrical, triploblastic and have a coelom. In addition, they show a new feature of body design, namely a notochord, at least at some stages during their lives. The notochord is a long rod-like support structure (chord=string) that runs along the back of the animal separating the nervous tissue from the gut. It provides a place for muscles to attach for ease of movement. Protochordates may not have a proper notochord present at all stages in their lives or for the entire length of the animal. Protochordates are marine animals. Examples are *Balanoglossus*, *Herdmania* and *Amphioxus* (see Fig. 7.20).

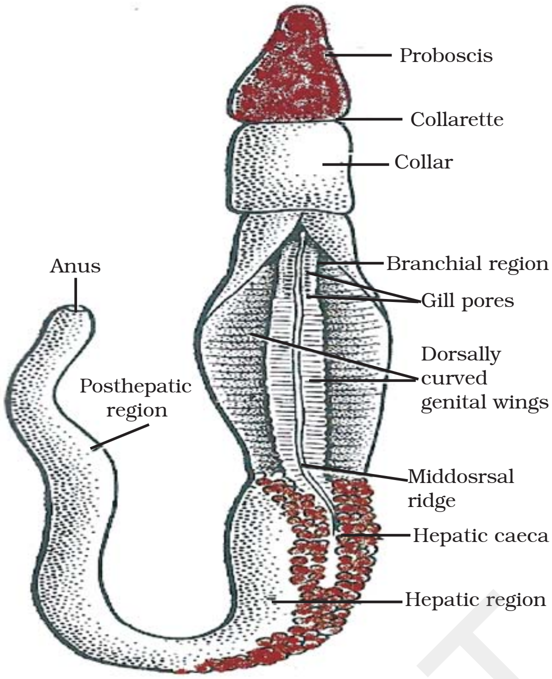


Fig. 7.20: *A Protochordata: Balanoglossus*

7.5.10 VERTEBRATA

These animals have a true vertebral column and internal skeleton, allowing a completely different distribution of muscle attachment points to be used for movement.

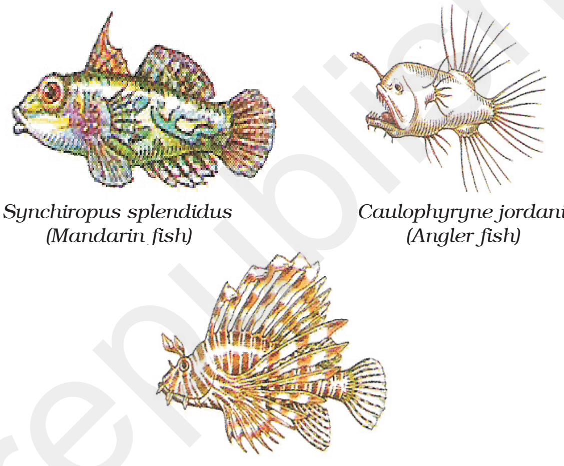
Vertebrates are bilaterally symmetrical, triploblastic, coelomic and segmented, with complex differentiation of body tissues and organs. All chordates possess the following features:

(i) have a notochord
(ii) have a dorsal nerve cord
(iii) are triploblastic
(iv) have paired gill pouches
(v) are coelomate.

Vertebrates are grouped into five classes.

7.5.10 (i) PISCES

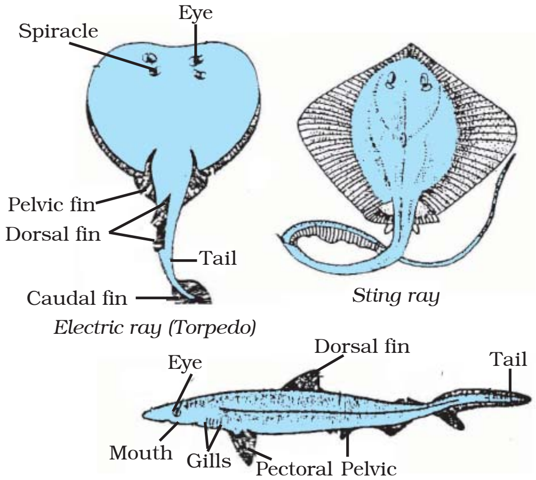
These are fish. They are exclusively aquatic animals. Their skin is covered with scales/ plates. They obtain oxygen dissolved in water by using gills. The body is streamlined, and a muscular tail is used for movement. They are cold-blooded and their hearts have only two chambers, unlike the four that humans have. They lay eggs. We can think of many kinds of fish, some with skeletons made entirely of cartilage, such as sharks, and some with a skeleton made of both bone and cartilage, such as tuna or rohu [see examples in Figs. 7.21 (a) and 7.21 (b)].



Synchiropus splendidus (Mandarin fish)

Caulophyryne jordani (Angler fish)

Pterois volitans (Lion fish)



Electric ray (Torpedo)

Sting ray

Scoliodon (Dog fish)

Fig. 7.21 (a): *Pisces*

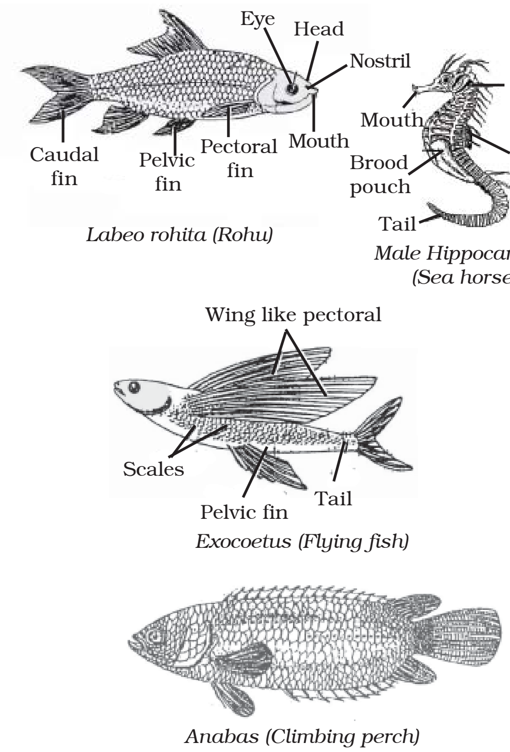


Fig. 7.21 (b): *Pisces*

7.5.10 (ii) Amphibia

These animals differ from the fish in the lack of scales, in having mucus glands in the skin, and a three-chambered heart. Respiration is through either gills or lungs. They lay eggs. These animals are found both in water and on land. Frogs, toads and salamanders are some examples (see Fig. 7.22).

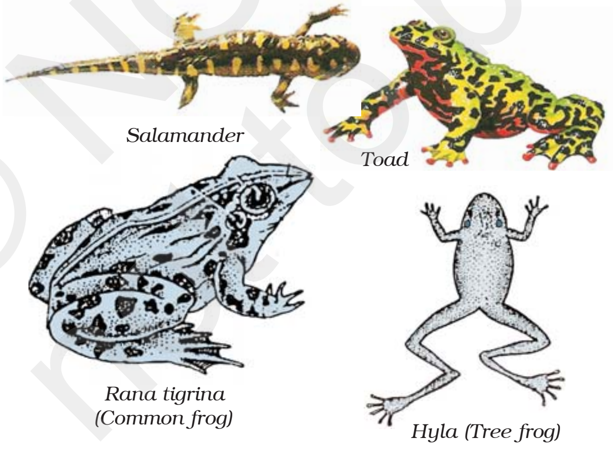


Fig. 7.22: *Amphibia*

7.5.10 (iii) Reptilia

These animals are cold-blooded, have scales and breathe through lungs. While most of them have a three-chambered heart, crocodiles have four heart chambers. They lay eggs with tough coverings and do not need to lay their eggs in water, unlike amphibians. Snakes, turtles, lizards and crocodiles fall in this category (see Fig. 7.23).

Fig. 7.23: *Reptilia*

7.5.10 (iv) Aves

These are warm-blooded animals and have a four-chambered heart. They lay eggs. There is an outside covering of feathers, and two forelimbs are modified for flight. They breathe through lungs. All birds fall in this category (see Fig. 7.24 for examples).

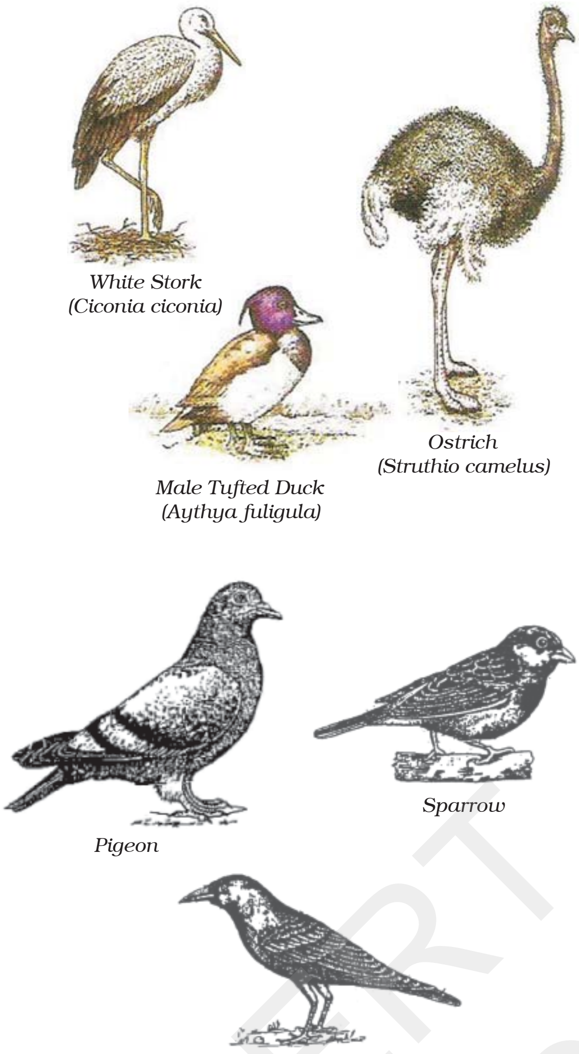


Fig. 7.24: *Aves (birds)*

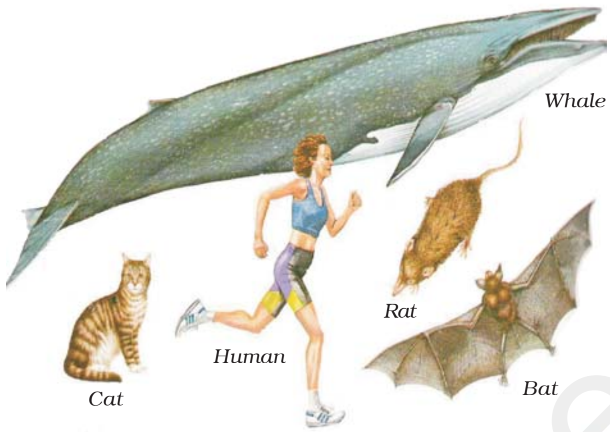


Fig. 7.25: *Mammalia*

7.5.10 (v) MAMMALIA

Mammals are warm-blooded animals with four-chambered hearts. They have mammary glands for the production of milk to nourish their young. Their skin has hairs as well as sweat and oil glands. Most mammals familiar to us produce live young ones. However, a few of them, like the platypus and the echidna lay eggs, and some, like kangaroos give birth to very poorly developed young ones. Some examples are shown in Fig. 7.25.

The scheme of classification of animals is shown in Fig. 7.26.

Questions

1. *How do poriferan animals differ from coelenterate animals?*
2. *How do annelid animals differ from arthropods?*
3. *What are the differences between amphibians and reptiles?*
4. *What are the differences between animals belonging to the Aves group and those in the mammalia group?*

Carolus Linnaeus (1707-1778)

Carolus Linnaeus (Karl von Linne) was born in Sweden and was a doctor by professsion. He was interested in the study of plants. At the age of 22, he published his first paper on plants. While serving as a personal physician of a wealthy government official, he studied the diversity of plants in his employer's garden. Later, he published 14 papers and also brought out the famous book *Systema Naturae* from which all fundamental taxonomical researches have taken off. His system of classification was a simple scheme for arranging plants so as to be able to identify them again.

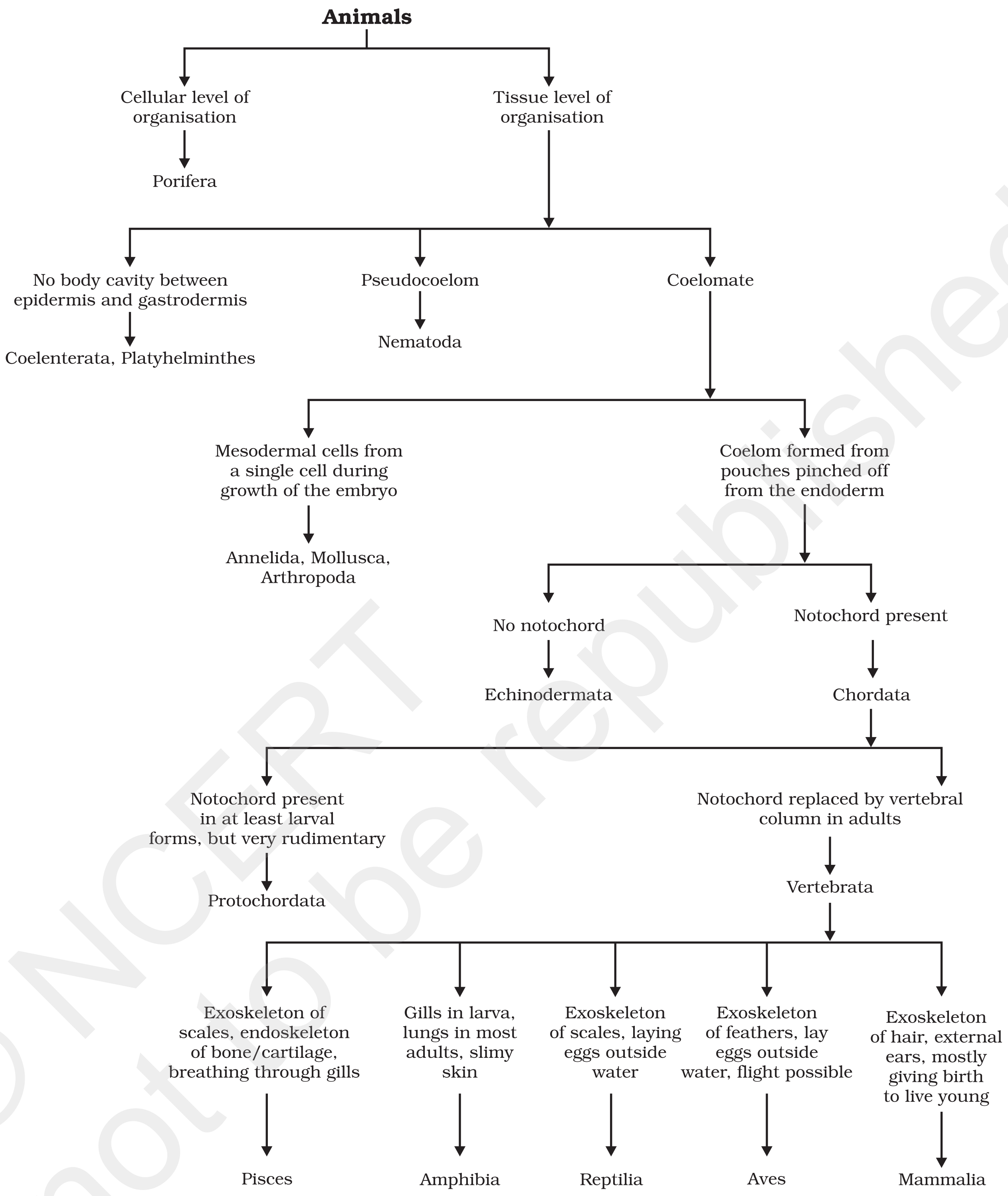


Fig. 7.26: *Classification of animals*

7.6 Nomenclature

Why is there a need for systematic naming of living organisms?

Activity 7.3

- Find out the names of the following animals and plants in as many languages as you can:

1. Tiger	2. Peacock	3. Ant
4. Neem	5. Lotus	6. Potato

As you might be able to appreciate, it would be difficult for people speaking or writing in different languages to know when they are talking about the same organism. This problem was resolved by agreeing upon a 'scientific' name for organisms in the same manner that chemical symbols and formulae for various substances are used the world over. The scientific name for an organism is thus unique and can be used to identify it anywhere in the world.

The system of scientific naming or nomenclature we use today was introduced by Carolus Linnaeus in the eighteenth century. The scientific name of an organism is the result of the process of classification which puts it along with the organisms it is most related to. But when we actually name the species, we do not list out the whole hierarchy of groups it belongs to. Instead, we limit ourselves to writing the name of the genus and species of that particular organism. The world over, it has been agreed that both these names will be used in Latin forms.

Certain conventions are followed while writing the scientific names:

1. The name of the genus begins with a capital letter.
2. The name of the species begins with a small letter.
3. When printed, the scientific name is given in italics.
4. When written by hand, the genus name and the species name have to be underlined separately.

Activity 7.4

- Find out the scientific names of any five common animals and plants. Do these names have anything in common with the names you normally use to identify them?

What you have learnt

- Classification helps us in exploring the diversity of life forms.
- The major characteristics considered for classifying all organisms into five major kingdoms are:
  - (a) whether they are made of prokaryotic or eukaryotic cells
  - (b) whether the cells are living singly or organised into multi-cellular and thus complex organisms
  - (c) whether the cells have a cell-wall and whether they prepare their own food.
- All living organisms are divided on the above bases into five kingdoms, namely Monera, Protista, Fungi, Plantae and Animalia.
- The classification of life forms is related to their evolution.

- Plantae and Animalia are further divided into subdivisions on the basis of increasing complexity of body organisation.
- Plants are divided into five groups: Thallophytes, Bryophytes, Pteridophytes, Gymnosperms and Angiosperms.
- Animals are divided into ten groups: Porifera, Coelenterata, Platyhelminthes, Nematoda, Annelida, Arthropoda, Mollusca, Echinodermata, Protochordata and Vertebrata.
- The binomial nomenclature makes for a uniform way of identification of the vast diversity of life around us.
- The binomial nomenclature is made up of two words – a generic name and a specific name.

Exercises

1. What are the advantages of classifying organisms?
2. How would you choose between two characteristics to be used for developing a hierarchy in classification?
3. Explain the basis for grouping organisms into five kingdoms.
4. What are the major divisions in the Plantae? What is the basis for these divisions?
5. How are the criteria for deciding divisions in plants different from the criteria for deciding the subgroups among animals?
6. Explain how animals in Vertebrata are classified into further subgroups.

Chapter 8

MOTION

In everyday life, we see some objects at rest and others in motion. Birds fly, fish swim, blood flows through veins and arteries and cars move. Atoms, molecules, planets, stars and galaxies are all in motion. We often perceive an object to be in motion when its position changes with time. However, there are situations where the motion is inferred through indirect evidences. For example, we infer the motion of air by observing the movement of dust and the movement of leaves and branches of trees. What causes the phenomena of sunrise, sunset and changing of seasons? Is it due to the motion of the earth? If it is true, why don't we directly perceive the motion of the earth?

An object may appear to be moving for one person and stationary for some other. For the passengers in a moving bus, the roadside trees appear to be moving backwards. A person standing on the road–side perceives the bus alongwith the passengers as moving. However, a passenger inside the bus sees his fellow passengers to be at rest. What do these observations indicate?

Most motions are complex. Some objects may move in a straight line, others may take a circular path. Some may rotate and a few others may vibrate. There may be situations involving a combination of these. In this chapter, we shall first learn to describe the motion of objects along a straight line. We shall also learn to express such motions through simple equations and graphs. Later, we shall discuss ways of describing circular motion.

Activity 8.1

- Discuss whether the walls of your classroom are at rest or in motion.

Activity 8.2

- Have you ever experienced that the train in which you are sitting appears to move while it is at rest?
- Discuss and share your experience.

Think and Act

We sometimes are endangered by the motion of objects around us, especially if that motion is erratic and uncontrolled as observed in a flooded river, a hurricane or a tsunami. On the other hand, controlled motion can be a service to human beings such as in the generation of hydro-electric power. Do you feel the necessity to study the erratic motion of some objects and learn to control them?

8.1 Describing Motion

We describe the location of an object by specifying a reference point. Let us understand this by an example. Let us assume that a school in a village is 2 km north of the railway station. We have specified the position of the school with respect to the railway station. In this example, the railway station is the reference point. We could have also chosen other reference points according to our convenience. Therefore, to describe the position of an object we need to specify a reference point called the origin.

8.1.1 Motion along a straight line

The simplest type of motion is the motion along a straight line. We shall first learn to describe this by an example. Consider the motion of an object moving along a straight path. The object starts its journey from O which is treated as its reference point (Fig. 8.1). Let A, B and C represent the position of the object at different instants. At first, the object moves through C and B and reaches A. Then it moves back along the same path and reaches C through B.

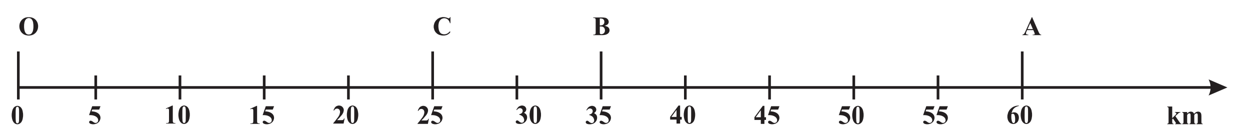


Fig. 8.1: *Positions of an object on a straight line path*

The total path length covered by the object is OA + AC, that is 60 km + 35 km = 95 km. This is the distance covered by the object. To describe distance we need to specify only the numerical value and not the direction of motion. There are certain quantities which are described by specifying only their numerical values. The numerical value of a physical quantity is its magnitude. From this example, can you find out the distance of the final position C of the object from the initial position O? This difference will give you the numerical value of the displacement of the object from O to C through A. The shortest distance measured from the initial to the final position of an object is known as the displacement.

Can the magnitude of the displacement be equal to the distance travelled by an object? Consider the example given in (Fig. 8.1). For motion of the object from O to A, the distance covered is 60 km and the magnitude of displacement is also 60 km. During its motion from O to A and back to B, the distance covered = 60 km + 25 km = 85 km while the magnitude of displacement = 35 km. Thus, the magnitude of displacement (35 km) is not equal to the path length (85 km). Further, we will notice that the magnitude of the displacement for a course of motion may be zero but the corresponding distance covered is not zero. If we consider the object to travel back to O, the final position concides with the initial position, and therefore, the displacement is zero. However, the distance covered in this journey is OA + AO = 60 km + 60 km = 120 km. Thus, two different physical quantities — the distance and the displacement, are used to describe the overall motion of an object and to locate its final position with reference to its initial position at a given time.

Activity 8.3

- Take a metre scale and a long rope.
- Walk from one corner of a basket-ball court to its oppposite corner along its sides.
- Measure the distance covered by you and magnitude of the displacement.
- What difference would you notice between the two in this case?

Activity 8.4

- Automobiles are fitted with a device that shows the distance travelled. Such a device is known as an odometer. A car is driven from Bhubaneshwar to New Delhi. The difference between the final reading and the initial reading of the odometer is 1850 km.
- Find the magnitude of the displacement between Bhubaneshwar and New Delhi by using the Road Map of India.

Questions

1. An object has moved through a distance. Can it have zero displacement? If yes, support your answer with an example.

2. A farmer moves along the boundary of a square field of side 10 m in 40 s. What will be the magnitude of displacement of the farmer at the end of 2 minutes 20 seconds from his initial position?

3. Which of the following is true for displacement?

(a) It cannot be zero.

(b) Its magnitude is greater than the distance travelled by the object.

8.1.2 Uniform motion and non-uniform motion

Consider an object moving along a straight line. Let it travel 5 m in the first second, 5 m more in the next second, 5 m in the third second and 5 m in the fourth second. In this case, the object covers 5 m in each second. As the object covers equal distances in equal intervals of time, it is said to be in uniform motion. The time interval in this motion should be small. In our day-to-day life, we come across motions where objects cover unequal distances in equal intervals of time, for example, when a car is moving on a crowded street or a person is jogging in a park. These are some instances of non-uniform motion.

Activity 8.5

- The data regarding the motion of two different objects A and B are given in Table 8.1.
- Examine them carefully and state whether the motion of the objects is uniform or non-uniform.

Table 8.1

Time	Distance travelled by object A in m	Distance travelled by object B in m
9:30 am	10	12
9:45 am	20	19
10:00 am	30	23
10:15 am	40	35
10:30 am	50	37
10:45 am	60	41
11:00 am	70	44

8.2 Measuring the Rate of Motion

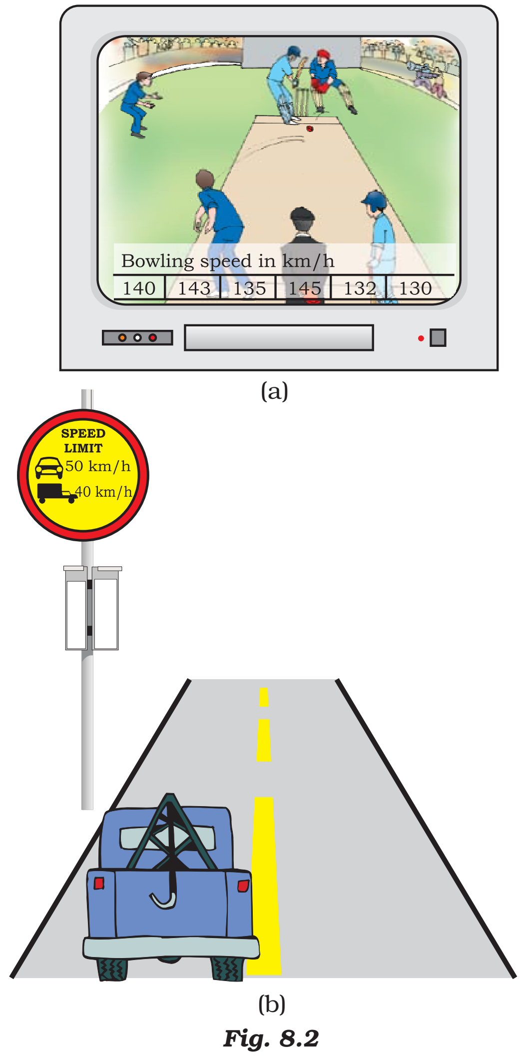


Fig. 8.2

Look at the situations given in Fig. 8.2. If the bowling speed is 143 km h^{-1} in Fig. 8.2(a) what does it mean? What do you understand from the signboard in Fig. 8.2(b)?

Different objects may take different amounts of time to cover a given distance. Some of them move fast and some move slowly. The rate at which objects move can be different. Also, different objects can move at the same rate. One of the ways of measuring the rate of motion of an object is to find out the distance travelled by the object in unit time. This quantity is referred to as speed. The SI unit of speed is metre per second. This is represented by the symbol m s^{-1} or m/s. The other units of speed include centimetre per second (cm s^{-1}) and kilometre per hour (km h^{-1}). To specify the speed of an object, we require only its magnitude. The speed of an object need not be constant. In most cases, objects will be in non-uniform motion. Therefore, we describe the rate of motion of such objects in terms of their average speed. The average speed of an object is obtained by dividing the total distance travelled by the total time taken. That is,

$$\text{average speed} = \frac{\text{Total distance travelled}}{\text{Total time taken}}$$

If an object travels a distance s in time t then its speed v is,

$$v = \frac{s}{t} \qquad (8.1)$$

Let us understand this by an example. A car travels a distance of 100 km in 2 h. Its average speed is 50 km h^{-1}. The car might not have travelled at 50 km h^{-1} all the time. Sometimes it might have travelled faster and sometimes slower than this.

Example 8.1 An object travels 16 m in 4 s and then another 16 m in 2 s. What is the average speed of the object?

Solution:

Total distance travelled by the object = 16 m + 16 m = 32 m

Total time taken = 4 s + 2 s = 6 s

$$\text{Average speed} = \frac{\text{Total distance travelled}}{\text{Total time taken}}$$

$$= \frac{32\ \text{m}}{6\ \text{s}} = 5.33\ \text{m s}^{-1}$$

Therefore, the average speed of the object is 5.33 m s^{-1}.

8.2.1 Speed with direction

The rate of motion of an object can be more comprehensive if we specify its direction of motion along with its speed. The quantity that specifies both these aspects is called velocity. Velocity is the speed of an object moving in a definite direction. The velocity of an object can be uniform or variable. It can be changed by changing the object's speed, direction of motion or both. When an object is moving along a straight line at a variable speed, we can express the magnitude of its rate of motion in terms of average velocity. It is calculated in the same way as we calculate average speed.

In case the velocity of the object is changing at a uniform rate, then average velocity is given by the arithmetic mean of initial velocity and final velocity for a given period of time. That is,

$$\text{average velocity} = \frac{\text{initial velocity} + \text{final velocity}}{2}$$

Mathematically, $$v_{av} = \frac{u + v}{2} \qquad (8.2)$$

where v_{av} is the average velocity, u is the initial velocity and v is the final velocity of the object.

Speed and velocity have the same units, that is, m s^{-1} or m/s.

Activity 8.6

- Measure the time it takes you to walk from your house to your bus stop or the school. If you consider that your average walking speed is 4 km h^{-1}, estimate the distance of the bus stop or school from your house.

Activity _______________ 8.7

- At a time when it is cloudy, there may be frequent thunder and lightning. The sound of thunder takes some time to reach you after you see the lightning.
- Can you answer why this happens?
- Measure this time interval using a digital wrist watch or a stop watch.
- Calculate the distance of the nearest point of lightning. (Speed of sound in air = 346 m s^{-1}.)

Questions

1. *Distinguish between speed and velocity.*
2. *Under what condition(s) is the magnitude of average velocity of an object equal to its average speed?*
3. *What does the odometer of an automobile measure?*
4. *What does the path of an object look like when it is in uniform motion?*
5. *During an experiment, a signal from a spaceship reached the ground station in five minutes. What was the distance of the spaceship from the ground station? The signal travels at the speed of light, that is, 3×10^8 m s^{-1}.*

Example 8.2 The odometer of a car reads 2000 km at the start of a trip and 2400 km at the end of the trip. If the trip took 8 h, calculate the average speed of the car in km h^{-1} and m s^{-1}.

Solution:

Distance covered by the car,

s = 2400 km – 2000 km = 400 km

Time elapsed, t = 8 h

Average speed of the car is,

$$v_{av} = \frac{s}{t} = \frac{400\text{ km}}{8\text{ h}}$$

$$= 50\text{ km h}^{-1}$$

$$= 50\frac{\text{km}}{\text{h}} \times \frac{1000\text{ m}}{1\text{ km}} \times \frac{1\text{ h}}{3600\text{ s}}$$

$$= 13.9\text{ m s}^{-1}$$

The average speed of the car is 50 km h^{-1} or 13.9 m s^{-1}.

Example 8.3 Usha swims in a 90 m long pool. She covers 180 m in one minute by swimming from one end to the other and back along the same straight path. Find the average speed and average velocity of Usha.

Solution:

Total distance covered by Usha in 1 min is 180 m.

Displacement of Usha in 1 min = 0 m

$$\text{Average speed} = \frac{\text{Total distance covered}}{\text{Total time taken}}$$

$$= \frac{180\text{ m}}{1\text{ min}} = \frac{180\text{ m}}{1\text{ min}} \times \frac{1\text{ min}}{60\text{ s}}$$

$$= 3\text{ m s}^{-1}$$

$$\text{Average velocity} = \frac{\text{Displacement}}{\text{Total time taken}}$$

$$= \frac{0\text{ m}}{60\text{ s}}$$

$$= 0\text{ m s}^{-1}$$

The average speed of Usha is 3 m s^{-1} and her average velocity is 0 m s^{-1}.

8.3 Rate of Change of Velocity

During uniform motion of an object along a straight line, the velocity remains constant with time. In this case, the change in velocity of the object for any time interval is zero. However, in non-uniform motion, velocity varies with time. It has different values at different instants and at different points of the path. Thus, the change in velocity of the object during any time interval is not zero. Can we now express the change in velocity of an object?

To answer such a question, we have to introduce another physical quantity called acceleration, which is a measure of the change in the velocity of an object per unit time. That is,

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time taken}}$$

If the velocity of an object changes from an initial value u to the final value v in time t, the acceleration a is,

$$a = \frac{v-u}{t} \qquad (8.3)$$

This kind of motion is known as accelerated motion. The acceleration is taken to be positive if it is in the direction of velocity and negative when it is opposite to the direction of velocity. The SI unit of acceleration is m s^{-2}.

If an object travels in a straight line and its velocity increases or decreases by equal amounts in equal intervals of time, then the acceleration of the object is said to be uniform. The motion of a freely falling body is an example of uniformly accelerated motion. On the other hand, an object can travel with non-uniform acceleration if its velocity changes at a non-uniform rate. For example, if a car travelling along a straight road increases its speed by unequal amounts in equal intervals of time, then the car is said to be moving with non-uniform acceleration.

Activity 8.8

- In your everyday life you come across a range of motions in which
  (a) acceleration is in the direction of motion,
  (b) acceleration is against the direction of motion,
  (c) acceleration is uniform,
  (d) acceleration is non-uniform.
- Can you identify one example each of the above type of motion?

Example 8.4 Starting from a stationary position, Rahul paddles his bicycle to attain a velocity of 6 m s^{-1} in 30 s. Then he applies brakes such that the velocity of the bicycle comes down to 4 m s^{-1} in the next 5 s. Calculate the acceleration of the bicycle in both the cases.

Solution:

In the first case:
initial velocity, $u = 0$;
final velocity, $v = 6$ m s^{-1} ;
time, $t = 30$ s .
From Eq. (8.3), we have

$$a = \frac{v-u}{t}$$

Substituting the given values of u,v and t in the above equation, we get

$$a = \frac{6\ \text{m s}^{-1} - 0\ \text{m s}^{-1}}{30\ \text{s}}$$

$$= 0.2\ \text{m s}^{-2}$$

In the second case:
initial velocity, $u = 6$ m s^{-1};
final velocity, $v = 4$ m s^{-1};
time, $t = 5$ s.

$$\text{Then, } a = \frac{4\ \text{m s}^{-1} - 6\ \text{m s}^{-1}}{5\ \text{s}}$$

$$= -0.4\ \text{m s}^{-2}.$$

The acceleration of the bicycle in the first case is 0.2 m s^{-2} and in the second case, it is –0.4 m s^{-2}.

Questions

1. *When will you say a body is in (i) uniform acceleration? (ii) non-uniform acceleration?*
2. *A bus decreases its speed from 80 km h^{-1} to 60 km h^{-1} in 5 s. Find the acceleration of the bus.*
3. *A train starting from a railway station and moving with uniform acceleration attains a speed 40 km h^{-1} in 10 minutes. Find its acceleration.*

8.4 Graphical Representation of Motion

Graphs provide a convenient method to present basic information about a variety of events. For example, in the telecast of a one-day cricket match, vertical bar graphs show the run rate of a team in each over. As you have studied in mathematics, a straight line graph helps in solving a linear equation having two variables.

To describe the motion of an object, we can use line graphs. In this case, line graphs show dependence of one physical quantity, such as distance or velocity, on another quantity, such as time.

8.4.1 Distance–time graphs

The change in the position of an object with time can be represented on the distance-time graph adopting a convenient scale of choice. In this graph, time is taken along the *x*–axis and distance is taken along the *y*-axis. Distance-time graphs can be employed under various conditions where objects move with uniform speed, non-uniform speed, remain at rest etc.

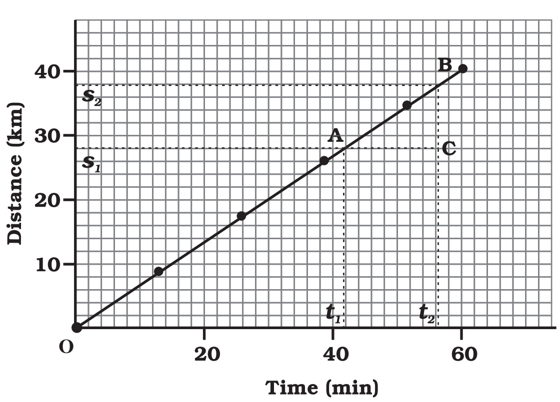


Fig. 8.3: *Distance-time graph of an object moving with uniform speed*

We know that when an object travels equal distances in equal intervals of time, it moves with uniform speed. This shows that the distance travelled by the object is directly proportional to time taken. Thus, for uniform speed, a graph of distance travelled against time is a straight line, as shown in Fig. 8.3. The portion OB of the graph shows that the distance is increasing at a uniform rate. Note that, you can also use the term uniform velocity in place of uniform speed if you take the magnitude of displacement equal to the distance travelled by the object along the *y*-axis.

We can use the distance-time graph to determine the speed of an object. To do so, consider a small part AB of the distance-time graph shown in Fig 8.3. Draw a line parallel to the *x*-axis from point A and another line parallel to the *y*-axis from point B. These two lines meet each other at point C to form a triangle ABC. Now, on the graph, AC denotes the time interval $(t_2 - t_1)$ while BC corresponds to the distance $(s_2 - s_1)$. We can see from the graph that as the object moves from the point A to B, it covers a distance $(s_2 - s_1)$ in time $(t_2 - t_1)$. The speed, v of the object, therefore can be represented as

$$v = \frac{s_2 - s_1}{t_2 - t_1} \qquad (8.4)$$

We can also plot the distance-time graph for accelerated motion. Table 8.2 shows the distance travelled by a car in a time interval of two seconds.

Table 8.2: Distance travelled by a car at regular time intervals

Time in seconds	Distance in metres
0	0
2	1
4	4
6	9
8	16
10	25
12	36

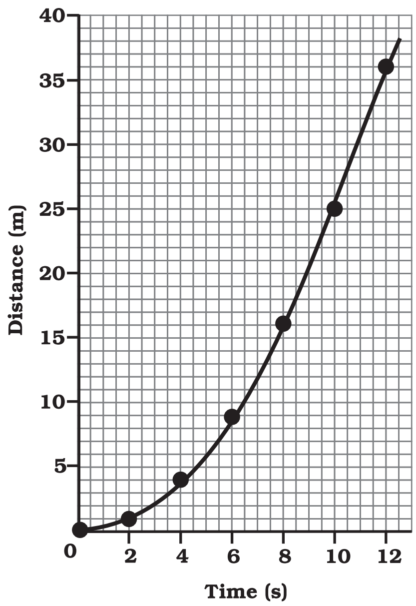


Fig. 8.4: *Distance-time graph for a car moving with non-uniform speed*

The distance-time graph for the motion of the car is shown in Fig. 8.4. Note that the shape of this graph is different from the earlier distance-time graph (Fig. 8.3) for uniform motion. The nature of this graph shows non-linear variation of the distance travelled by the car with time. Thus, the graph shown in Fig 8.4 represents motion with non-uniform speed.

8.4.2 VELOCITY-TIME GRAPHS

The variation in velocity with time for an object moving in a straight line can be represented by a velocity-time graph. In this graph, time is represented along the x-axis

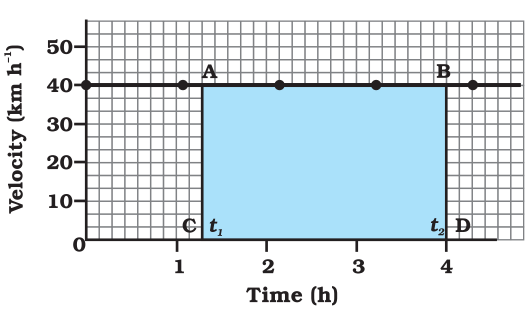


Fig. 8.5: *Velocity-time graph for uniform motion of a car*

and the velocity is represented along the y-axis. If the object moves at uniform velocity, the height of its velocity-time graph will not change with time (Fig. 8.5). It will be a straight line parallel to the x-axis. Fig. 8.5 shows the velocity-time graph for a car moving with uniform velocity of 40 km h^{-1}.

We know that the product of velocity and time give displacement of an object moving with uniform velocity. The area enclosed by velocity-time graph and the time axis will be equal to the magnitude of the displacement.

To know the distance moved by the car between time t_1 and t_2 using Fig. 8.5, draw perpendiculars from the points corresponding to the time t_1 and t_2 on the graph. The velocity of 40 km h^{-1} is represented by the height AC or BD and the time $(t_2 - t_1)$ is represented by the length AB.

So, the distance s moved by the car in time $(t_2 - t_1)$ can be expressed as

$$s = AC \times CD$$
$$= [(40 \text{ km h}^{-1}) \times (t_2 - t_1) \text{ h}]$$
$$= 40 \, (t_2 - t_1) \text{ km}$$
= area of the rectangle ABDC (shaded in Fig. 8.5).

We can also study about uniformly accelerated motion by plotting its velocity–time graph. Consider a car being driven along a straight road for testing its engine. Suppose a person sitting next to the driver records its velocity after every 5 seconds by noting the reading of the speedometer of the car. The velocity of the car, in km h^{-1} as well as in m s^{-1}, at different instants of time is shown in table 8.3.

Table 8.3: Velocity of a car at regular instants of time

Time (s)	Velocity of the car (m s^{-1})	(km h^{-1})
0	0	0
5	2.5	9
10	5.0	18
15	7.5	27
20	10.0	36
25	12.5	45
30	15.0	54

In this case, the velocity-time graph for the motion of the car is shown in Fig. 8.6. The nature of the graph shows that velocity changes by equal amounts in equal intervals of time. Thus, for all uniformly accelerated motion, the velocity-time graph is a straight line.

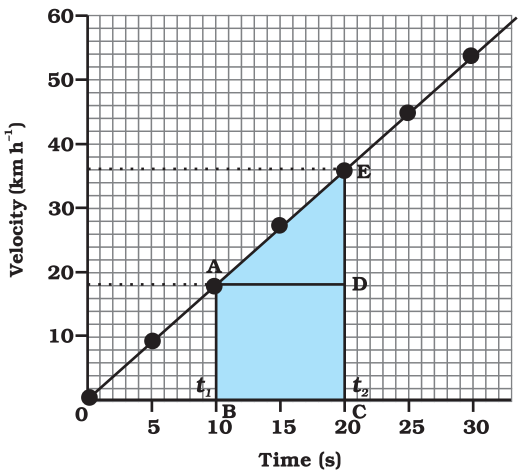


Fig. 8.6: *Velocity-time graph for a car moving with uniform accelerations.*

You can also determine the distance moved by the car from its velocity-time graph. The area under the velocity-time graph gives the distance (magnitude of displacement) moved by the car in a given interval of time. If the car would have been moving with uniform velocity, the distance travelled by it would be represented by the area ABCD under the graph (Fig. 8.6). Since the magnitude of the velocity of the car is changing due to acceleration, the distance s travelled by the car will be given by the area ABCDE under the velocity-time graph (Fig. 8.6).

That is,

s = area ABCDE

= area of the rectangle ABCD + area of the triangle ADE

$= AB \times BC + \frac{1}{2}(AD \times DE)$

In the case of non-uniformly accelerated motion, velocity-time graphs can have any shape.

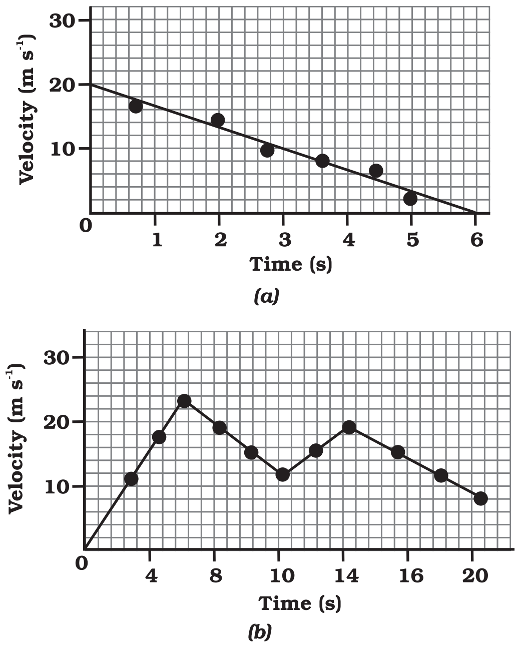


Fig. 8.7: *Velocity-time graphs of an object in non-uniformly accelerated motion.*

Fig. 8.7(a) shows a velocity-time graph that represents the motion of an object whose velocity is decreasing with time while Fig. 8.7 (b) shows the velocity-time graph representing the non-uniform variation of velocity of the object with time. Try to interpret these graphs.

Activity ______________ *8.9*

- The times of arrival and departure of a train at three stations A, B and C and the distance of stations B and C from station A are given in table 8.4.

Table 8.4: Distances of stations B and C from A and times of arrival and departure of the train

Station	Distance from A (km)	Time of arrival (hours)	Time of departure (hours)
A	0	08:00	08:15
B	120	11:15	11:30
C	180	13:00	13:15

- Plot and interpret the distance-time graph for the train assuming that its motion between any two stations is uniform.

Activity ______________ 8.10

- Feroz and his sister Sania go to school on their bicycles. Both of them start at the same time from their home but take different times to reach the school although they follow the same route. Table 8.5 shows the distance travelled by them in different times

Table 8.5: Distance covered by Feroz and Sania at different times on their bicycles

Time	Distance travelled by Feroz (km)	Distance travelled by Sania (km)
8:00 am	0	0
8:05 am	1.0	0.8
8:10 am	1.9	1.6
8:15 am	2.8	2.3
8:20 am	3.6	3.0
8:25 am	–	3.6

- Plot the distance-time graph for their motions on the same scale and interpret.

Questions

1. *What is the nature of the distance-time graphs for uniform and non-uniform motion of an object?*
2. *What can you say about the motion of an object whose distance-time graph is a straight line parallel to the time axis?*
3. *What can you say about the motion of an object if its speed-time graph is a straight line parallel to the time axis?*
4. *What is the quantity which is measured by the area occupied below the velocity-time graph?*

8.5 Equations of Motion by Graphical Method

When an object moves along a straight line with uniform acceleration, it is possible to relate its velocity, acceleration during motion and the distance covered by it in a certain time interval by a set of equations known as the equations of motion. There are three such equations. These are:

$$v = u + at \qquad (8.5)$$

$$s = ut + ½\, at^2 \qquad (8.6)$$

$$2\,a\,s = v^2 – u^2 \qquad (8.7)$$

where u is the initial velocity of the object which moves with uniform acceleration a for time t, v is the final velocity, and s is the distance travelled by the object in time t. Eq. (8.5) describes the velocity-time relation and Eq. (8.6) represents the position-time relation. Eq. (8.7), which represents the relation between the position and the velocity, can be obtained from Eqs. (8.5) and (8.6) by eliminating t. These three equations can be derived by graphical method.

8.5.1 Equation for velocity-time relation

Consider the velocity-time graph of an object that moves under uniform acceleration as

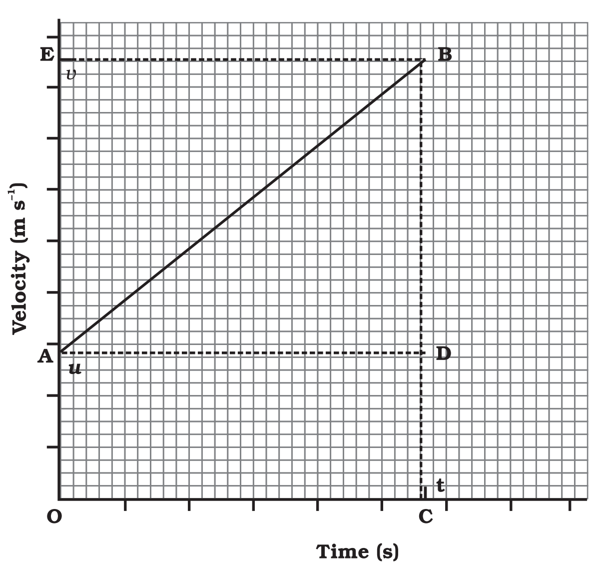


Fig. 8.8: *Velocity-time graph to obtain the equations of motion*

shown in Fig. 8.8 (similar to Fig. 8.6, but now with $u \neq 0$). From this graph, you can see that initial velocity of the object is u (at point A) and then it increases to v (at point B) in time t. The velocity changes at a uniform rate a. In Fig. 8.8, the perpendicular lines BC and BE are drawn from point B on the time and the velocity axes respectively, so that the initial velocity is represented by OA, the final velocity is represented by BC and the time interval t is represented by OC. BD = BC – CD, represents the change in velocity in time interval t.

Let us draw AD parallel to OC. From the graph, we observe that

BC = BD + DC = BD + OA

Substituting BC $= v$ and OA $= u$,

we get $v = \text{BD} + u$

or $\text{BD} = v - u$ (8.8)

From the velocity-time graph (Fig. 8.8), the acceleration of the object is given by

$$a = \frac{\text{Change in velocity}}{\text{time taken}}$$

$$= \frac{\text{BD}}{\text{AD}} = \frac{\text{BD}}{\text{OC}}$$

Substituting OC $= t$, we get

$$a = \frac{\text{BD}}{t}$$

or $\text{BD} = at$ (8.9)

Using Eqs. (8.8) and (8.9) we get

$$v = u + at$$

8.5.2 Equation for position-time Relation

Let us consider that the object has travelled a distance s in time t under uniform acceleration a. In Fig. 8.8, the distance travelled by the object is obtained by the area enclosed within OABC under the velocity-time graph AB.

Thus, the distance s travelled by the object is given by

s = area OABC (which is a trapezium)

= area of the rectangle OADC + area of the triangle ABD

$$= \text{OA} \times \text{OC} + \frac{1}{2}(\text{AD} \times \text{BD}) \quad (8.10)$$

Substituting OA $= u$, OC = AD $= t$ and BD $= at$, we get

$$s = u \times t + \frac{1}{2}(t \times at)$$

or $$s = u\,t + \frac{1}{2}\,a\,t^2$$

8.5.3 Equation for position–velocity relation

From the velocity-time graph shown in Fig. 8.8, the distance s travelled by the object in time t, moving under uniform acceleration a is given by the area enclosed within the trapezium OABC under the graph. That is,

s = area of the trapezium OABC

$$= \frac{(\text{OA} + \text{BC}) \times \text{OC}}{2}$$

Substituting OA $= u$, BC $= v$ and OC $= t$, we get

$$s = \frac{(u + v)\,t}{2} \quad (8.11)$$

From the velocity-time relation (Eq. 8.6), we get

$$t = \frac{v - u}{a} \quad (8.12)$$

Using Eqs. (8.11) and (8.12) we have

$$s = \frac{(v + u)(v - u)}{2a}$$

or $$2\,a\,s = v^2 - u^2$$

Example 8.5 A train starting from rest attains a velocity of 72 km h^{-1} in 5 minutes. Assuming that the acceleration is uniform, find (i) the acceleration and (ii) the distance travelled by the train for attaining this velocity.

Solution:

We have been given
$u = 0$; $v = 72$ km h^{-1} = 20 m s^{-1} and
$t = 5$ minutes = 300 s.

(i) From Eq. (8.5) we know that

$$a = \frac{v - u}{t}$$

$$= \frac{20 \text{ m s}^{-1} - 0 \text{ m s}^{-1}}{300 \text{ s}}$$

$$= \frac{1}{15} \text{ m s}^{-2}$$

(ii) From Eq. (8.7) we have
$2\,a\,s = v^2 - u^2 = v^2 - 0$
Thus,

$$s = \frac{v^2}{2a}$$

$$= \frac{(20 \text{ m s}^{-1})^2}{2 \times (1/15) \text{ m s}^{-2}}$$

$= 3000$ m
$= 3$ km

The acceleration of the train is $\frac{1}{15}$ m s^{-2} and the distance travelled is 3 km.

Example 8.6 A car accelerates uniformly from 18 km h^{-1} to 36 km h^{-1} in 5 s. Calculate (i) the acceleration and (ii) the distance covered by the car in that time.

Solution:

We are given that
u = 18 km h^{-1} = 5 m s^{-1}
v = 36 km h^{-1} = 10 m s^{-1} and
t = 5 s .

(i) From Eq. (8.5) we have

$$a = \frac{v - u}{t}$$

$$= \frac{10 \text{ m s}^{-1} - 5 \text{ m s}^{-1}}{5 \text{ s}}$$

$= 1$ m s^{-2}

(ii) From Eq. (8.6) we have

$$s = u\,t + \frac{1}{2}\,a\,t^2$$

$$= 5 \text{ m s}^{-1} \times 5 \text{ s} + \frac{1}{2} \times 1 \text{ m s}^{-2} \times (5 \text{ s})^2$$

$= 25$ m + 12.5 m

$= 37.5$ m

The acceleration of the car is 1 m s^{-2} and the distance covered is 37.5 m.

Example 8.7 The brakes applied to a car produce an acceleration of 6 m s^{-2} in the opposite direction to the motion. If the car takes 2 s to stop after the application of brakes, calculate the distance it travels during this time.

Solution:

We have been given
$a = -6$ m s^{-2} ; $t = 2$ s and $v = 0$ m s^{-1}.
From Eq. (8.5) we know that
$v = u + at$
$0 = u + (-6 \text{ m s}^{-2}) \times 2$ s
or $u = 12$ m s^{-1} .
From Eq. (8.6) we get

$$s = u\,t + \frac{1}{2}\,a\,t^2$$

$$= (12 \text{ m s}^{-1}) \times (2 \text{ s}) + \frac{1}{2}(-6 \text{ m s}^{-2})(2 \text{ s})^2$$

$= 24$ m – 12 m
$= 12$ m

Thus, the car will move 12 m before it stops after the application of brakes. Can you now appreciate why drivers are cautioned to maintain some distance between vehicles while travelling on the road?

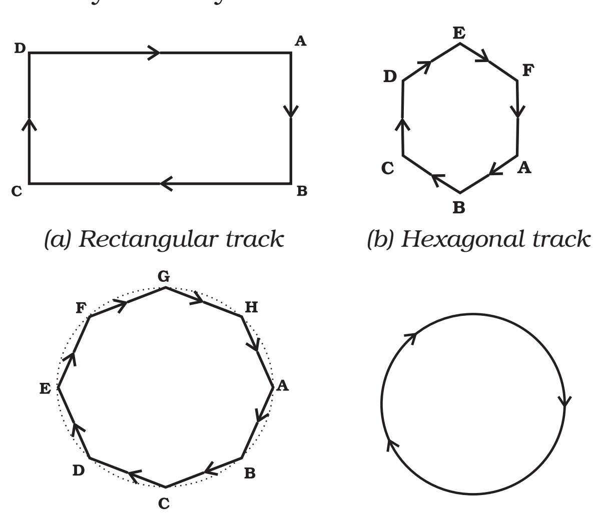
Questions

1. A bus starting from rest moves with a uniform acceleration of 0.1 m s^{-2} for 2 minutes. Find (a) the speed acquired, (b) the distance travelled.

2. *A train is travelling at a speed of 90 km h^{-1}. Brakes are applied so as to produce a uniform acceleration of – 0.5 m s^{-2}. Find how far the train will go before it is brought to rest.*
3. *A trolley, while going down an inclined plane, has an acceleration of 2 cm s^{-2}. What will be its velocity 3 s after the start?*
4. *A racing car has a uniform acceleration of 4 m s^{-2}. What distance will it cover in 10 s after start?*
5. *A stone is thrown in a vertically upward direction with a velocity of 5 m s^{-1}. If the acceleration of the stone during its motion is 10 m s^{-2} in the downward direction, what will be the height attained by the stone and how much time will it take to reach there?*

8.6 Uniform Circular Motion

When the velocity of an object changes, we say that the object is accelerating. The change in the velocity could be due to change in its magnitude or the direction of the motion or both. Can you think of an example when an object does not change its magnitude of velocity but only its direction of motion?



(a) Rectangular track *(b) Hexagonal track*

(c) Octagonal shaped track *(d) A circular track*

Fig. 8.9: *The motion of an athlete along closed tracks of different shapes.*

Let us consider an example of the motion of a body along a closed path. Fig 8.9 (a) shows the path of an athlete along a rectangular track ABCD. Let us assume that the athlete runs at a uniform speed on the straight parts AB, BC, CD and DA of the track. In order to keep himself on track, he quickly changes his speed at the corners. How many times will the athlete have to change his direction of motion, while he completes one round? It is clear that to move in a rectangular track once, he has to change his direction of motion four times.

Now, suppose instead of a rectangular track, the athlete is running along a hexagonal shaped path ABCDEF, as shown in Fig. 8.9(b). In this situation, the athlete will have to change his direction six times while he completes one round. What if the track was not a hexagon but a regular octagon, with eight equal sides as shown by ABCDEFGH in Fig. 8.9(c)? It is observed that as the number of sides of the track increases the athelete has to take turns more and more often. What would happen to the shape of the track as we go on increasing the number of sides indefinitely? If you do this you will notice that the shape of the track approaches the shape of a circle and the length of each of the sides will decrease to a point. If the athlete moves with a velocity of constant magnitude along the circular path, the only change in his velocity is due to the change in the direction of motion. The motion of the athlete moving along a circular path is, therefore, an example of an accelerated motion.

We know that the circumference of a circle of radius r is given by $2\ r$. If the athlete takes t seconds to go once around the circular path of radius r, the velocity v is given by

$$v = \frac{2\ r}{t} \qquad (8.13)$$

When an object moves in a circular path with uniform speed, its motion is called uniform circular motion.

Activity ______________ *8.11*

- Take a piece of thread and tie a small piece of stone at one of its ends. Move the stone to describe a circular path with constant speed by holding the thread at the other end, as shown in Fig. 8.10.

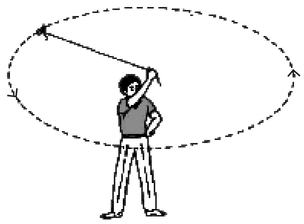


Fig. 8.10: *A stone describing a circular path with a velocity of constant magnitude.*

- Now, let the stone go by releasing the thread.
- Can you tell the direction in which the stone moves after it is released?
- By repeating the activity for a few times and releasing the stone at different positions of the circular path, check whether the direction in which the stone moves remains the same or not.

If you carefully note, on being released the stone moves along a straight line tangential to the circular path. This is because once the stone is released, it continues to move along the direction it has been moving at that instant. This shows that the direction of motion changed at every point when the stone was moving along the circular path.

When an athlete throws a hammer or a discus in a sports meet, he/she holds the hammer or the discus in his/her hand and gives it a circular motion by rotating his/her own body. Once released in the desired direction, the hammer or discus moves in the direction in which it was moving at the time it was released, just like the piece of stone in the activity described above. There are many more familiar examples of objects moving under uniform circular motion, such as the motion of the moon and the earth, a satellite in a circular orbit around the earth, a cyclist on a circular track at constant speed and so on.

What you have learnt

- Motion is a change of position; it can be described in terms of the distance moved or the displacement.
- The motion of an object could be uniform or non-uniform depending on whether its velocity is constant or changing.
- The speed of an object is the distance covered per unit time, and velocity is the displacement per unit time.
- The acceleration of an object is the change in velocity per unit time.
- Uniform and non-uniform motions of objects can be shown through graphs.
- The motion of an object moving at uniform acceleration can be described with the help of three equations, namely

$$v = u + at$$

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

$$2as = v^2 - u^2$$

where u is initial velocity of the object, which moves with uniform acceleration a for time t, v is its final velocity and s is the distance it travelled in time t.

- If an object moves in a circular path with uniform speed, its motion is called uniform circular motion.

Exercises

1. An athlete completes one round of a circular track of diameter 200 m in 40 *s*. What will be the distance covered and the displacement at the end of 2 minutes 20 s?
2. Joseph jogs from one end A to the other end B of a straight 300 m road in 2 minutes 30 seconds and then turns around and jogs 100 m back to point C in another 1 minute. What are Joseph's average speeds and velocities in jogging (a) from A to B and (b) from A to C?
3. Abdul, while driving to school, computes the average speed for his trip to be 20 km h^{-1}. On his return trip along the same route, there is less traffic and the average speed is 30 km h^{-1}. What is the average speed for Abdul's trip?
4. A motorboat starting from rest on a lake accelerates in a straight line at a constant rate of 3.0 m s^{-2} for 8.0 s. How far does the boat travel during this time?
5. A driver of a car travelling at 52 km h^{-1} applies the brakes and accelerates uniformly in the opposite direction. The car stops in 5 s. Another driver going at 3 km h^{-1} in another car applies his brakes slowly and stops in 10 s. On the same graph paper, plot the speed versus time graphs for the two cars. Which of the two cars travelled farther after the brakes were applied?
6. Fig 8.11 shows the distance-time graph of three objects A,B and C. Study the graph and answer the following questions:

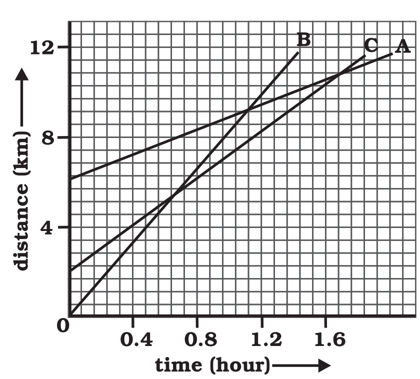


Fig. 8.11

(a) Which of the three is travelling the fastest?

(b) Are all three ever at the same point on the road?

(c) How far has C travelled when B passes A?

(d) How far has B travelled by the time it passes C?

7. A ball is gently dropped from a height of 20 m. If its velocity increases uniformly at the rate of 10 m s^{-2}, with what velocity will it strike the ground? After what time will it strike the ground?

8. The speed-time graph for a car is shown is Fig. 8.12.

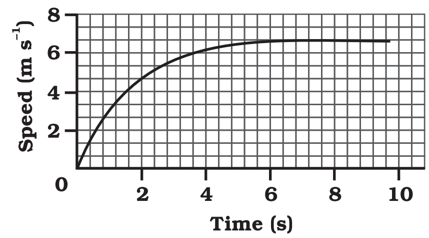


Fig. 8.12

(a) Find how far does the car travel in the first 4 seconds. Shade the area on the graph that represents the distance travelled by the car during the period.

(b) Which part of the graph represents uniform motion of the car?

9. State which of the following situations are possible and give an example for each of these:

(a) an object with a constant acceleration but with zero velocity

(b) an object moving in a certain direction with an acceleration in the perpendicular direction.

10. An artificial satellite is moving in a circular orbit of radius 42250 km. Calculate its speed if it takes 24 hours to revolve around the earth.

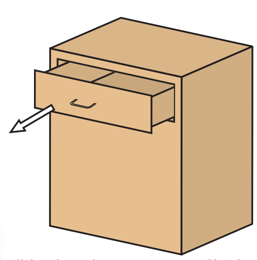
Chapter 9

Force and Laws of Motion

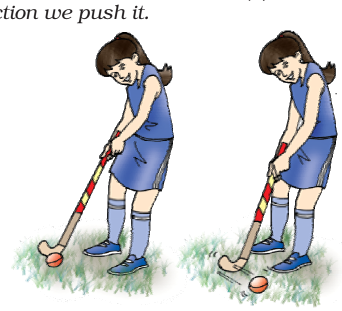
In the previous chapter, we described the motion of an object along a straight line in terms of its position, velocity and acceleration. We saw that such a motion can be uniform or non-uniform. We have not yet discovered what causes the motion. Why does the speed of an object change with time? Do all motions require a cause? If so, what is the nature of this cause? In this chapter we shall make an attempt to quench all such curiosities.

For many centuries, the problem of motion and its causes had puzzled scientists and philosophers. A ball on the ground, when given a small hit, does not move forever. Such observations suggest that rest is the "natural state" of an object. This remained the belief until Galileo Galilei and Isaac Newton developed an entirely different approach to understand motion.

(a) The trolley moves along the direction we push it.



(b) The drawer is pulled.

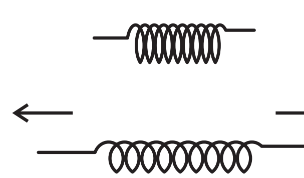


(c) The hockey stick hits the ball forward

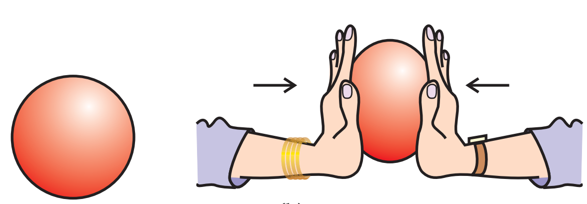
Fig. 9.1: *Pushing, pulling, or hitting objects change their state of motion.*

In our everyday life we observe that some effort is required to put a stationary object into motion or to stop a moving object. We ordinarily experience this as a muscular effort and say that we must push or hit or pull on an object to change its state of motion. The concept of force is based on this push, hit or pull. Let us now ponder about a 'force'. What is it? In fact, no one has seen, tasted or felt a force. However, we always see or feel the effect of a force. It can only be explained by describing what happens when a force is applied to an object. Pushing, hitting and pulling of objects are all ways of bringing objects in motion (Fig. 9.1). They move because we make a force act on them.

From your studies in earlier classes, you are also familiar with the fact that a force can be used to change the magnitude of velocity of an object (that is, to make the object move faster or slower) or to change its direction of motion. We also know that a force can change the shape and size of objects (Fig. 9.2).



(a)



(b)

Fig. 9.2: (a) *A spring expands on application of force;* (b) *A spherical rubber ball becomes oblong as we apply force on it.*

9.1 Balanced and Unbalanced Forces

Fig. 9.3 shows a wooden block on a horizontal table. Two strings X and Y are tied to the two opposite faces of the block as shown. If we apply a force by pulling the string X, the block begins to move to the right. Similarly, if we pull the string Y, the block moves to the left. But, if the block is pulled from both the sides with equal forces, the block will not move. Such forces are called balanced forces and do not change the state of rest or of motion of an object. Now, let us consider a situation in which two opposite forces of different magnitudes pull the block. In this case, the block would begin to move in the direction of the greater force. Thus, the two forces are not balanced and the unbalanced force acts in the direction the block moves. This suggests that an unbalanced force acting on an object brings it in motion.

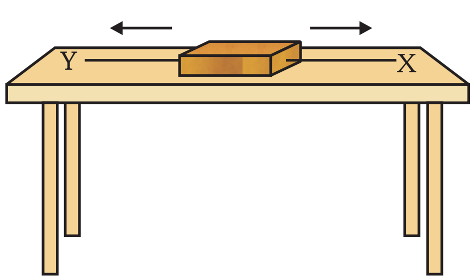


Fig. 9.3: *Two forces acting on a wooden block*

What happens when some children try to push a box on a rough floor? If they push the box with a small force, the box does not move because of friction acting in a direction opposite to the push [Fig. 9.4(a)]. This friction force arises between two surfaces in contact; in this case, between the bottom of the box and floor's rough surface. It balances the pushing force and therefore the box does not move. In Fig. 9.4(b), the children push the box harder but the box still does not move. This is because the friction force still balances the pushing force. If the children push the box harder still, the pushing force becomes bigger than the friction force [Fig. 9.4(c)]. There is an unbalanced force. So the box starts moving.

What happens when we ride a bicycle? When we stop pedalling, the bicycle begins to slow down. This is again because of the friction forces acting opposite to the direction of motion. In order to keep the bicycle moving, we have to start pedalling again. It thus appears that an object maintains its motion under the continuous application of an unbalanced force. However, it is quite incorrect. An object moves with a uniform velocity when the forces (pushing force and frictional force) acting on the object are balanced and there is no net external force on it. If an unbalanced force is applied on the object, there will be a change either in its speed or in the direction of its motion. Thus, to accelerate the motion of an object, an unbalanced force is required. And the change in its speed (or in the direction of motion) would continue as long as this unbalanced force is applied. However, if this force is

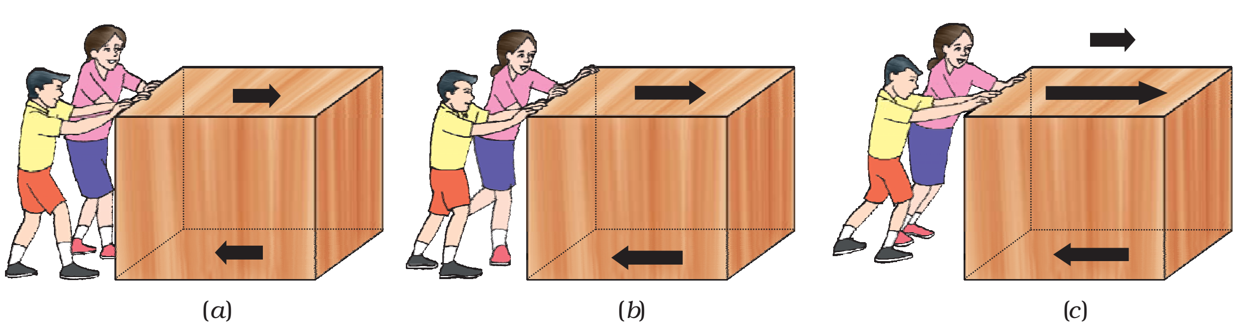


Fig. 9.4

removed completely, the object would continue to move with the velocity it has acquired till then.

9.2 First Law of Motion

By observing the motion of objects on an inclined plane Galileo deduced that objects move with a constant speed when no force acts on them. He observed that when a marble rolls down an inclined plane, its velocity increases [Fig. 9.5(a)]. In the next chapter, you will learn that the marble falls under the unbalanced force of gravity as it rolls down and attains a definite velocity by the time it reaches the bottom. Its velocity decreases when it climbs up as shown in Fig. 9.5(b). Fig. 9.5(c) shows a marble resting on an ideal frictionless plane inclined on both sides. Galileo argued that when the marble is released from left, it would roll down the slope and go up on the opposite side to the same height from which it was released. If the inclinations of the planes on both sides are equal then the marble will climb the same distance that it covered while rolling down. If the angle of inclination of the right-side plane were gradually decreased, then the marble would travel further distances till it reaches the original height. If the right-side plane were ultimately made horizontal (that is, the slope is reduced to zero), the marble would continue to travel forever trying to reach the same height that it was released from. The unbalanced forces on the marble in this case are zero. It thus suggests that an unbalanced (external) force is required to change the motion of the marble but no net force is needed to sustain the uniform motion of the marble. In practical situations it is difficult to achieve a zero unbalanced force. This is because of the presence of the frictional force acting opposite to the direction of motion. Thus, in practice the marble stops after travelling some distance. The effect of the frictional force may be minimised by using a smooth marble and a smooth plane and providing a lubricant on top of the planes.

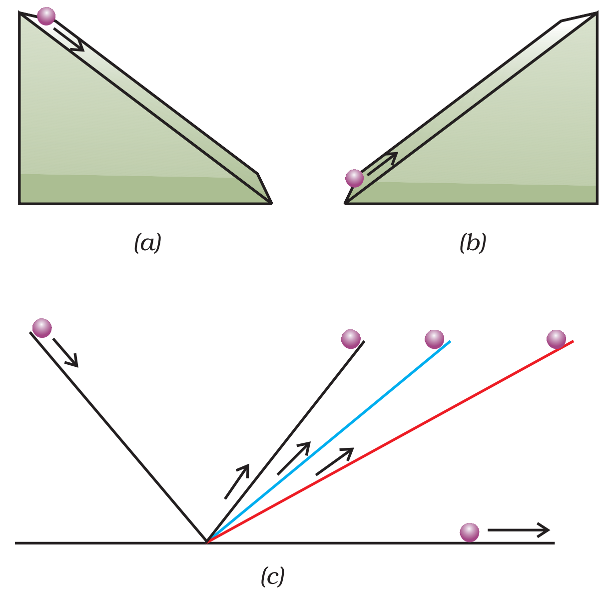


Fig. 9.5: *(a) the downward motion; (b) the upward motion of a marble on an inclined plane; and (c) on a double inclined plane.*

Newton further studied Galileo's ideas on force and motion and presented three fundamental laws that govern the motion of objects. These three laws are known as Newton's laws of motion. The first law of motion is stated as:

An object remains in a state of rest or of uniform motion in a straight line unless compelled to change that state by an applied force.

In other words, all objects resist a change in their *state of motion*. In a qualitative way, the tendency of undisturbed objects to stay at rest or to keep moving with the same velocity is called inertia. This is why, the first law of motion is also known as the law of inertia.

Certain experiences that we come across while travelling in a motorcar can be explained on the basis of the law of inertia. We tend to remain at rest with respect to the seat until the driver applies a braking force to stop the motorcar. With the application of brakes, the car slows down but our body tends to continue in the same state of motion because of its inertia. A sudden application of brakes may thus cause injury to us by

Galileo Galilei
(1564 – 1642)

Galileo Galilei was born on 15 February 1564 in Pisa, Italy. Galileo, right from his childhood, had interest in mathematics and natural philosophy. But his father Vincenzo Galilei wanted him to become a medical doctor. Accordingly, Galileo enrolled himself for a medical degree at the University of Pisa in 1581 which he never completed because of his real interest in mathematics. In 1586, he wrote his first scientific book *'The Little Balance* [*La Balancitta*]', in which he described Archimedes' method of finding the relative densities (or specific gravities) of substances using a balance. In 1589, in his series of essays – *De Motu*, he presented his theories about falling objects using an inclined plane to slow down the rate of descent.

In 1592, he was appointed professor of mathematics at the University of Padua in the Republic of Venice. Here he continued his observations on the theory of motion and through his study of inclined planes and the pendulum, formulated the correct law for uniformly accelerated objects that the distance the object moves is proportional to the square of the time taken.

Galileo was also a remarkable craftsman. He developed a series of telescopes whose optical performance was much better than that of other telescopes available during those days. Around 1640, he designed the first pendulum clock. In his book *'Starry Messenger'* on his astronomical discoveries, Galileo claimed to have seen mountains on the moon, the milky way made up of tiny stars, and four small bodies orbiting Jupiter. In his books *'Discourse on Floating Bodies'* and *'Letters on the Sunspots'*, he disclosed his observations of sunspots.

Using his own telescopes and through his observations on Saturn and Venus, Galileo argued that all the planets must orbit the Sun and not the earth, contrary to what was believed at that time.

impact or collision with the panels in front. Safety belts are worn to prevent such accidents. Safety belts exert a force on our body to make the forward motion slower. An opposite experience is encountered when we are standing in a bus and the bus begins to move suddenly. Now we tend to fall backwards. This is because the sudden start of the bus brings motion to the bus as well as to our feet in contact with the floor of the bus. But the rest of our body opposes this motion because of its inertia.

When a motorcar makes a sharp turn at a high speed, we tend to get thrown to one side. This can again be explained on the basis of the law of inertia. We tend to continue in our straight-line motion. When an unbalanced force is applied by the engine to change the direction of motion of the motorcar, we slip to one side of the seat due to the inertia of our body.

The fact that a body will remain at rest unless acted upon by an unbalanced force can be illustrated through the following activities:

Activity ____________ 9.1

- Make a pile of similar carom coins on a table, as shown in Fig. 9.6.
- Attempt a sharp horizontal hit at the bottom of the pile using another carom coin or the striker. If the hit is strong enough, the bottom coin moves out quickly. Once the lowest coin is removed, the inertia of the other coins makes them 'fall' vertically on the table.

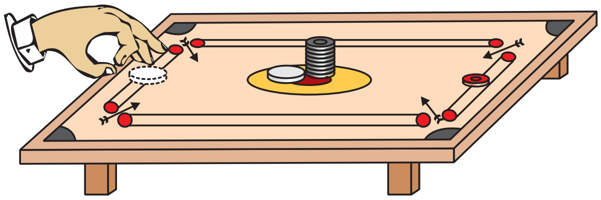


Fig. 9.6: *Only the carom coin at the bottom of a pile is removed when a fast moving carom coin (or striker) hits it.*

Activity _____________ 9.2

- Set a five-rupee coin on a stiff card covering an empty glass tumbler standing on a table as shown in Fig. 9.7.
- Give the card a sharp horizontal flick with a finger. If we do it fast then the card shoots away, allowing the coin to fall vertically into the glass tumbler due to its inertia.
- The inertia of the coin tries to maintain its state of rest even when the card flows off.

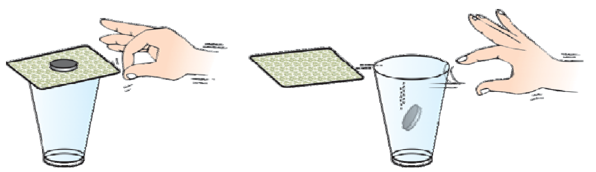


Fig. 9.7: *When the card is flicked with the finger the coin placed over it falls in the tumbler.*

Activity _____________ 9.3

- Place a water-filled tumbler on a tray.
- Hold the tray and turn around as fast as you can.
- We observe that the water spills. Why?

Observe that a groove is provided in a saucer for placing the tea cup. It prevents the cup from toppling over in case of sudden jerks.

9.3 Inertia and Mass

All the examples and activities given so far illustrate that there is a resistance offered by an object to change its state of motion. If it is at rest it tends to remain at rest; if it is moving it tends to keep moving. This property of an object is called its inertia. Do all bodies have the same inertia? We know that it is easier to push an empty box than a box full of books. Similarly, if we kick a football it flies away. But if we kick a stone of the same size with equal force, it hardly moves. We may, in fact, get an injury in our foot while doing so! Similarly, in activity 9.2, instead of a five-rupees coin if we use a one-rupee coin, we find that a lesser force is required to perform the activity. A force that is just enough to cause a small cart to pick up a large velocity will produce a negligible change in the motion of a train. This is because, in comparison to the cart the train has a much lesser tendency to change its state of motion. Accordingly, we say that the train has more inertia than the cart. Clearly, heavier or more massive objects offer larger inertia. Quantitatively, the inertia of an object is measured by its mass. We may thus relate inertia and mass as follows: Inertia is the natural tendency of an object to resist a change in its state of motion or of rest. The mass of an object is a measure of its inertia.

Questions

1. *Which of the following has more inertia: (a) a rubber ball and a stone of the same size? (b) a bicycle and a train? (c) a five-rupees coin and a one-rupee coin?*
2. *In the following example, try to identify the number of times the velocity of the ball changes: "A football player kicks a football to another player of his team who kicks the football towards the goal. The goalkeeper of the opposite team collects the football and kicks it towards a player of his own team". Also identify the agent supplying the force in each case.*
3. *Explain why some of the leaves may get detached from a tree if we vigorously shake its branch.*
4. *Why do you fall in the forward direction when a moving bus brakes to a stop and fall backwards when it accelerates from rest?*

9.4 Second Law of Motion

The first law of motion indicates that when an unbalanced external force acts on an object, its velocity changes, that is, the object gets an acceleration. We would now like to study how the acceleration of an object depends on the force applied to it and how we measure a force. Let us recount some observations from our everyday life. During the game of table tennis if the ball hits a player it does not hurt him. On the other hand, when a fast moving cricket ball hits a spectator, it may hurt him. A truck at rest does not require any attention when parked along a roadside. But a moving truck, even at speeds as low as 5 m s^{-1}, may kill a person standing in its path. A small mass, such as a bullet may kill a person when fired from a gun. These observations suggest that the impact produced by the objects depends on their mass and velocity. Similarly, if an object is to be accelerated, we know that a greater force is required to give a greater velocity. In other words, there appears to exist some quantity of importance that combines the object's mass and its velocity. One such property called momentum was introduced by Newton. The momentum, p of an object is defined as the product of its mass, m and velocity, v. That is,

$$p = mv \qquad (9.1)$$

Momentum has both direction and magnitude. Its direction is the same as that of velocity, v. The SI unit of momentum is kilogram-metre per second (kg m s^{-1}). Since the application of an unbalanced force brings a change in the velocity of the object, it is therefore clear that a force also produces a change of momentum.

Let us consider a situation in which a car with a dead battery is to be pushed along a straight road to give it a speed of 1 m s^{-1}, which is sufficient to start its engine. If one or two persons give a sudden push (unbalanced force) to it, it hardly starts. But a continuous push over some time results in a gradual acceleration of the car to this speed. It means that the change of momentum of the car is not only determined by the magnitude of the force but also by the time during which the force is exerted. It may then also be concluded that the force necessary to change the momentum of an object depends on the time rate at which the momentum is changed.

The second law of motion states that the rate of change of momentum of an object is proportional to the applied unbalanced force in the direction of force.

9.4.1 Mathematical formulation of second law of motion

Suppose an object of mass, m is moving along a straight line with an initial velocity, u. It is uniformly accelerated to velocity, v in time, t by the application of a constant force, F throughout the time, t. The initial and final momentum of the object will be, $p_1 = mu$ and $p_2 = mv$ respectively.

The change in momentum $\propto p_2 - p_1$
$\propto mv - mu$
$\propto m \times (v - u)$.

The rate of change of momentum $\propto \dfrac{m \times (v-u)}{t}$

Or, the applied force,

$$F \propto \frac{m \times (v-u)}{t}$$

$$F = \frac{km \times (v-u)}{t} \qquad (9.2)$$

$$= kma \qquad (9.3)$$

Here a [= $(v - u)/t$] is the acceleration, which is the rate of change of velocity. The quantity, k is a constant of proportionality. The SI units of mass and acceleration are kg and m s^{-2} respectively. The unit of force is so chosen that the value of the constant, k becomes one. For this, one unit of force is defined as the amount that produces an acceleration of 1 m s^{-2} in an object of 1 kg mass. That is,

1 unit of force = $k \times (1\ \text{kg}) \times (1\ \text{m s}^{-2})$.

Thus, the value of k becomes 1. From Eq. (9.3)

$$F = ma \qquad (9.4)$$

The unit of force is kg m s^{-2} or newton, which has the symbol N. The second law of motion gives us a method to measure the force acting on an object as a product of its mass and acceleration.

The second law of motion is often seen in action in our everyday life. Have you noticed that while catching a fast moving cricket ball, a fielder in the ground gradually pulls his hands backwards with the moving ball? In doing so, the fielder increases the time during which the high velocity of the moving ball decreases to zero. Thus, the acceleration of the ball is decreased and therefore the impact of catching the fast moving ball (Fig. 9.8) is also reduced. If the ball is stopped suddenly then its high velocity decreases to zero in a very short interval of time. Thus, the rate of change of momentum of the ball will be large. Therefore, a large force would have to be applied for holding the catch that may hurt the palm of the fielder. In a high jump athletic event, the athletes are made to fall either on a cushioned bed or on a sand bed. This is to increase the time of the athlete's fall to stop after making the jump. This decreases the rate of change of momentum and hence the force. Try to ponder how a karate player breaks a slab of ice with a single blow.

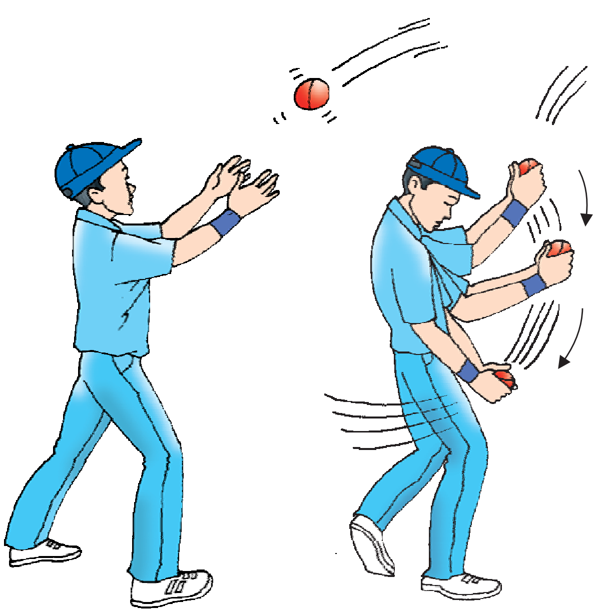


Fig. 9.8: *A fielder pulls his hands gradually with the moving ball while holding a catch.*

The first law of motion can be mathematically stated from the mathematical expression for the second law of motion. Eq. (9.4) is

$$F = ma$$

$$\text{or} \quad F = \frac{m(v-u)}{t} \tag{9.5}$$

$$\text{or} \quad Ft = mv - mu$$

That is, when $F = 0$, $v = u$ for whatever time, t is taken. This means that the object will continue moving with uniform velocity, u throughout the time, t. If u is zero then v will also be zero. That is, the object will remain at rest.

Example 9.1 A constant force acts on an object of mass 5 kg for a duration of 2 s. It increases the object's velocity from 3 m s^{-1} to 7 m s^{-1}. Find the magnitude of the applied force. Now, if the force was applied for a duration of 5 s, what would be the final velocity of the object?

Solution:

We have been given that u = 3 m s^{-1} and v = 7 m s^{-1}, t = 2 s and m = 5 kg. From Eq. (9.5) we have,

$$F = \frac{m(v-u)}{t}$$

Substitution of values in this relation gives

F = 5 kg (7 m s^{-1} – 3 m s^{-1})/2 s = 10 N.

Now, if this force is applied for a duration of 5 s (t = 5 s), then the final velocity can be calculated by rewriting Eq. (9.5) as

$$v = u + \frac{Ft}{m}$$

On substituting the values of u, F, m and t, we get the final velocity,

v = 13 m s^{-1}.

Example 9.2 Which would require a greater force — accelerating a 2 kg mass at 5 m s^{-2} or a 4 kg mass at 2 m s^{-2}?

Solution:

From Eq. (9.4), we have $F = ma$.
Here we have $m_1 = 2$ kg; $a_1 = 5$ m s^{-2} and $m_2 = 4$ kg; $a_2 = 2$ m s^{-2}.
Thus, $F_1 = m_1a_1 = 2\text{ kg} \times 5\text{ m s}^{-2} = 10$ N;
and $F_2 = m_2a_2 = 4\text{ kg} \times 2\text{ m s}^{-2} = 8$ N.
$\Rightarrow F_1 > F_2$.
Thus, accelerating a 2 kg mass at 5 m s^{-2} would require a greater force.

Example 9.3 A motorcar is moving with a velocity of 108 km/h and it takes 4 s to stop after the brakes are applied. Calculate the force exerted by the brakes on the motorcar if its mass along with the passengers is 1000 kg.

Solution:

The initial velocity of the motorcar
$u = 108$ km/h
$= 108 \times 1000\text{ m}/(60 \times 60\text{ s})$
$= 30\text{ m s}^{-1}$
and the final velocity of the motorcar
$v = 0\text{ m s}^{-1}$.
The total mass of the motorcar along with its passengers = 1000 kg and the time taken to stop the motorcar, $t = 4$ s.
From Eq. (9.5) we have the magnitude of the force (F) applied by the brakes as $m(v - u)/t$.
On substituting the values, we get
$F = 1000\text{ kg} \times (0 - 30)\text{ m s}^{-1}/4\text{ s}$
$= -7500\text{ kg m s}^{-2}$ or -7500 N.
The negative sign tells us that the force exerted by the brakes is opposite to the direction of motion of the motorcar.

Example 9.4 A force of 5 N gives a mass m_1, an acceleration of 10 m s^{-2} and a mass m_2, an acceleration of 20 m s^{-2}. What acceleration would it give if both the masses were tied together?

Solution:

From Eq. (9.4) we have $m_1 = F/a_1$; and $m_2 = F/a_2$. Here, $a_1 = 10$ m s^{-2};
$a_2 = 20$ m s^{-2} and $F = 5$ N.
Thus, $m_1 = 5\text{ N}/10\text{ m s}^{-2} = 0.50$ kg; and
$m_2 = 5\text{ N}/20\text{ m s}^{-2} = 0.25$ kg.
If the two masses were tied together, the total mass, m would be
$m = 0.50\text{ kg} + 0.25\text{ kg} = 0.75$ kg.
The acceleration, a produced in the combined mass by the 5 N force would be, $a = F/m = 5\text{ N}/0.75\text{ kg} = 6.67\text{ m s}^{-2}$.

Example 9.5 The velocity-time graph of a ball of mass 20 g moving along a straight line on a long table is given in Fig. 9.9.

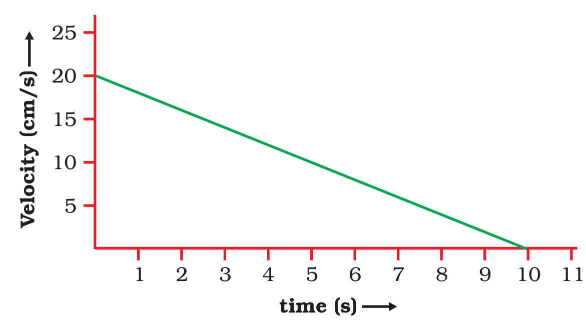


Fig. 9.9

How much force does the table exert on the ball to bring it to rest?

Solution:

The initial velocity of the ball is 20 cm s^{-1}. Due to the friction force exerted by the table, the velocity of the ball decreases down to zero in 10 s. Thus, $u = 20$ cm s^{-1}; $v = 0$ cm s^{-1} and $t = 10$ s. Since the velocity-time graph is a straight line, it is clear that the ball moves with a constant acceleration. The acceleration a is

$$a = \frac{v - u}{t}$$

$= (0\text{ cm s}^{-1} - 20\text{ cm s}^{-1})/10\text{ s}$
$= -2\text{ cm s}^{-2} = -0.02\text{ m s}^{-2}$.

The force exerted on the ball F is,

$F = ma = (20/1000)\ \text{kg} \times (-\ 0.02\ \text{m s}^{-2})$

$= -\ 0.0004$ N.

The negative sign implies that the frictional force exerted by the table is opposite to the direction of motion of the ball.

9.5 Third Law of Motion

The first two laws of motion tell us how an applied force changes the motion and provide us with a method of determining the force. The third law of motion states that when one object exerts a force on another object, the second object instantaneously exerts a force back on the first. These two forces are always equal in magnitude but opposite in direction. These forces act on different objects and never on the same object. In the game of football sometimes we, while looking at the football and trying to kick it with a greater force, collide with a player of the opposite team. Both feel hurt because each applies a force to the other. In other words, there is a pair of forces and not just one force. The two opposing forces are also known as action and reaction forces.

Let us consider two spring balances connected together as shown in Fig. 9.10. The fixed end of balance B is attached with a rigid support, like a wall. When a force is applied through the free end of spring balance A, it is observed that both the spring balances show the same readings on their scales. It means that the force exerted by spring balance A on balance B is equal but opposite in direction to the force exerted by the balance B on balance A. The force which balance A exerts on balance B is called the *action* and the force of balance B on balance A is called the *reaction*. This gives us an alternative statement of the third law of motion i.e., to every action there is an equal and opposite reaction. However, it must be remembered that the action and reaction always act on two different objects.

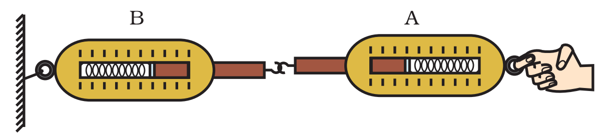


Fig. 9.10: *Action and reaction forces are equal and opposite.*

Suppose you are standing at rest and intend to start walking on a road. You must accelerate, and this requires a force in accordance with the second law of motion. Which is this force? Is it the muscular effort you exert on the road? Is it in the direction we intend to move? No, you push the road below backwards. The road exerts an equal and opposite reaction force on your feet to make you move forward.

It is important to note that even though the action and reaction forces are always equal in magnitude, these forces may not produce accelerations of equal magnitudes. This is because each force acts on a different object that may have a different mass.

When a gun is fired, it exerts a forward force on the bullet. The bullet exerts an equal and opposite reaction force on the gun. This results in the recoil of the gun (Fig. 9.11). Since the gun has a much greater mass than the bullet, the acceleration of the gun is much less than the acceleration of the bullet. The third law of motion can also be illustrated when a sailor jumps out of a rowing boat. As the sailor jumps forward, the force on the boat moves it backwards (Fig. 9.12).

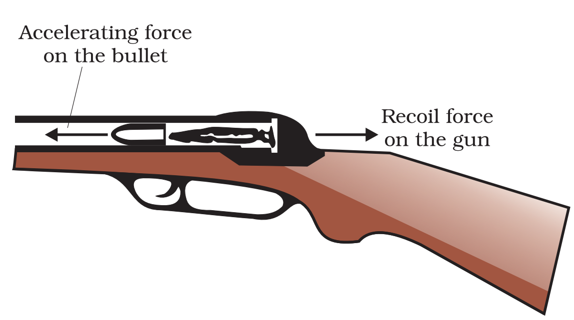


Fig. 9.11: *A forward force on the bullet and recoil of the gun.*

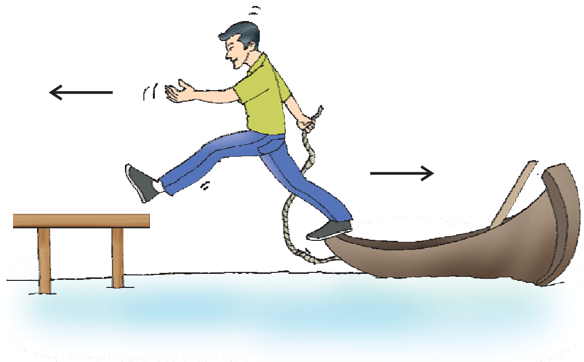


Fig. 9.12: *As the sailor jumps in forward direction, the boat moves backwards.*

Activity ______________ *9.4*

- Request two children to stand on two separate carts as shown in Fig. 9.13.
- Give them a bag full of sand or some other heavy object. Ask them to play a game of catch with the bag.
- Does each of them receive an instantaneous reaction as a result of throwing the sand bag (action)?
- You can paint a white line on cartwheels to observe the motion of the two carts when the children throw the bag towards each other.

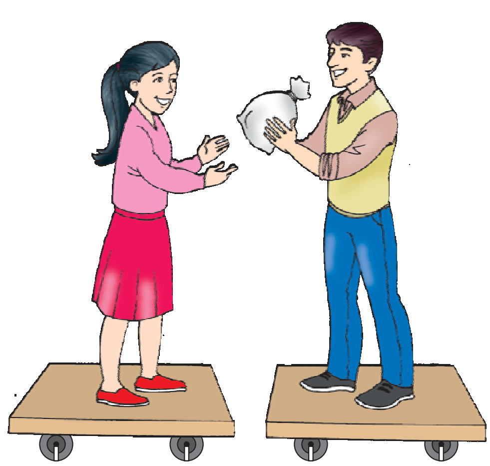


Fig. 9.13

Now, place two children on one cart and one on another cart. The second law of motion can be seen, as this arrangement would show different accelerations for the same force.

The cart shown in this activity can be constructed by using a 12 mm or 18 mm thick plywood board of about 50 cm × 100 cm with two pairs of hard ball-bearing wheels (skate wheels are good to use). Skateboards are not as effective because it is difficult to maintain straight-line motion.

9.6 Conservation of Momentum

Suppose two objects (two balls A and B, say) of masses m_A and m_B are travelling in the same direction along a straight line at different velocities u_A and u_B, respectively [Fig. 9.14(a)]. And there are no other external unbalanced forces acting on them. Let $u_A > u_B$ and the two balls collide with each other as shown in Fig. 9.14(b). During collision which lasts for a time t, the ball A exerts a force F_{AB} on ball B and the ball B exerts a force F_{BA} on ball A. Suppose v_A and v_B are the velocities of the two balls A and B after the collision, respectively [Fig. 9.14(c)].

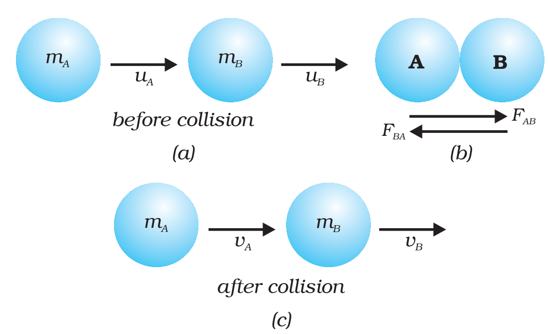


Fig. 9.14: *Conservation of momentum in collision of two balls.*

From Eq. (9.1), the momenta (plural of momentum) of ball A before and after the collision are $m_A u_A$ and $m_A v_A$, respectively. The rate of change of its momentum (or F_{AB}, action) during the collision will be $m_A \frac{(v_A - u_A)}{t}$.

Similarly, the rate of change of momentum of ball B (= F_{BA} or reaction) during the collision will be $m_B \frac{(v_B - u_B)}{t}$.

According to the third law of motion, the force F_{AB} exerted by ball A on ball B (action) and the force F_{BA} exerted by the ball B on ball A (reaction) must be equal and opposite to each other. Therefore,

$$F_{AB} = - F_{BA} \quad (9.6)$$

or $$m_A \frac{(v_A - u_A)}{t} = - m_B \frac{(v_B - u_B)}{t}.$$

This gives,

$$m_A u_A + m_B u_B = m_A v_A + m_B v_B \quad (9.7)$$

Since $(m_A u_A + m_B u_B)$ is the total momentum of the two balls A and B before the collision and $(m_A v_A + m_B v_B)$ is their total momentum after the collision, from Eq. (9.7) we observe that the total momentum of the two balls remains unchanged or conserved provided no other external force acts.

As a result of this ideal collision experiment, we say that the sum of momenta of the two objects before collision is equal to the sum of momenta after the collision provided there is no external unbalanced force acting on them. This is known as the law of conservation of momentum. This statement can alternatively be given as the total momentum of the two objects is unchanged or conserved by the collision.

Activity 9.5

- Take a big rubber balloon and inflate it fully. Tie its neck using a thread. Also using adhesive tape, fix a straw on the surface of this balloon.
- Pass a thread through the straw and hold one end of the thread in your hand or fix it on the wall.
- Ask your friend to hold the other end of the thread or fix it on a wall at some distance. This arrangement is shown in Fig. 9.15.
- Now remove the thread tied on the neck of balloon. Let the air escape from the mouth of the balloon.
- Observe the direction in which the straw moves.

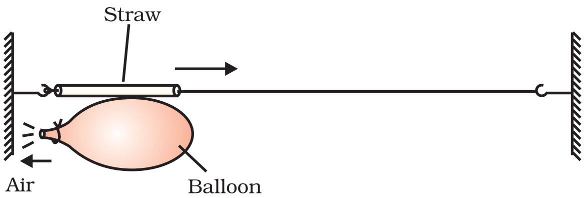
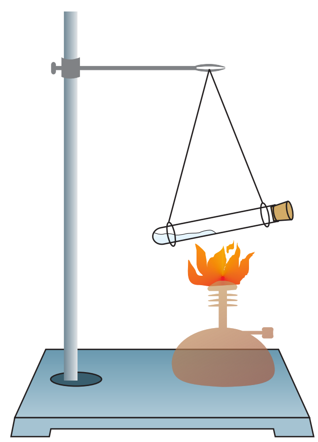


Fig. 9.15

Activity 9.6

- Take a test tube of good quality glass material and put a small amount of water in it. Place a stop cork at the mouth of it.
- Now suspend the test tube horizontally by two strings or wires as shown in Fig. 9.16.
- Heat the test tube with a burner until water vaporises and the cork blows out.
- Observe that the test tube recoils in the direction opposite to the direction



of the cork.

Fig. 9.16

- Also, observe the difference in the velocity the cork appears to have and that of the recoiling test tube.

Example 9.6 A bullet of mass 20 g is horizontally fired with a velocity 150 m s^{-1} from a pistol of mass 2 kg. What is the recoil velocity of the pistol?

Solution:

We have the mass of bullet, m_1 = 20 g (= 0.02 kg) and the mass of the pistol, m_2 = 2 kg; initial velocities of the bullet (u_1) and pistol (u_2) = 0, respectively. The final velocity of the bullet, v_1 = + 150 m s^{-1}. The direction of bullet is taken from left to right (positive, by convention, Fig. 9.17). Let v be the recoil velocity of the pistol.

Total momenta of the pistol and bullet before the fire, when the gun is at rest

$= (2 + 0.02)\ \text{kg} \times 0\ \text{m s}^{-1}$

$= 0\ \text{kg m s}^{-1}$

Total momenta of the pistol and bullet after it is fired

$= 0.02\ \text{kg} \times (+\ 150\ \text{m s}^{-1}) + 2\ \text{kg} \times v\ \text{m s}^{-1}$

$= (3 + 2v)\ \text{kg m s}^{-1}$

According to the law of conservation of momentum

Total momenta after the fire = Total momenta before the fire

$3 + 2v = 0$

$\Rightarrow v = -1.5\ \text{m s}^{-1}$.

Negative sign indicates that the direction in which the pistol would recoil is opposite to that of bullet, that is, right to left.

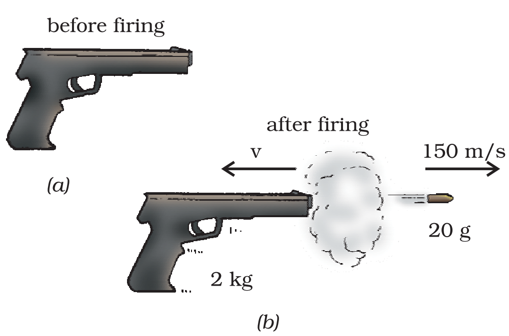


Fig. 9.17: *Recoil of a pistol*

Example 9.7 A girl of mass 40 kg jumps with a horizontal velocity of 5 m s^{-1} onto a stationary cart with frictionless wheels. The mass of the cart is 3 kg. What is her velocity as the cart starts moving? Assume that there is no external unbalanced force working in the horizontal direction.

Solution:

Let v be the velocity of the girl on the cart as the cart starts moving.

The total momenta of the girl and cart before the interaction

$= 40\ \text{kg} \times 5\ \text{m s}^{-1} + 3\ \text{kg} \times 0\ \text{m s}^{-1}$

$= 200\ \text{kg m s}^{-1}$.

Total momenta after the interaction

$= (40 + 3)\ \text{kg} \times v\ \text{m s}^{-1}$

$= 43\ v\ \text{kg m s}^{-1}$.

According to the law of conservation of momentum, the total momentum is conserved during the interaction. That is,

$43\ v = 200$

$\Rightarrow v = 200/43 = +\ 4.65\ \text{m s}^{-1}$.

The girl on cart would move with a velocity of 4.65 m s^{-1} in the direction in which the girl jumped (Fig. 9.18).

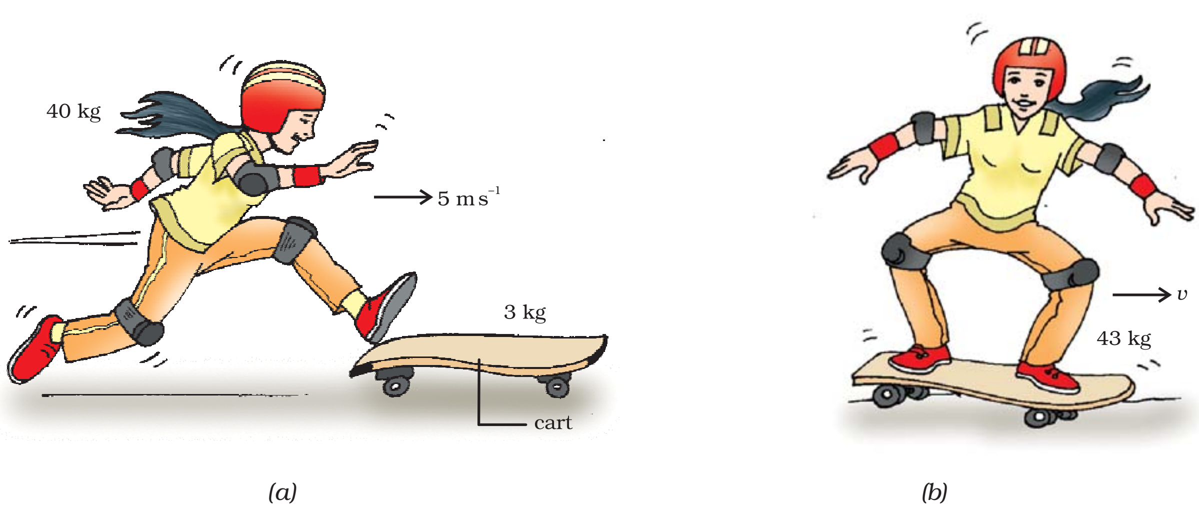


Fig. 9.18: *The girl jumps onto the cart.*

Example 9.8 Two hockey players of opposite teams, while trying to hit a hockey ball on the ground collide and immediately become entangled. One has a mass of 60 kg and was moving with a velocity 5.0 m s^{-1} while the other has a mass of 55 kg and was moving faster with a velocity 6.0 m s^{-1} towards the first player. In which direction and with what velocity will they move after they become entangled? Assume that the frictional force acting between the feet of the two players and ground is negligible.

Solution:

Let the first player be moving from left to right. By convention left to right is taken as the positive direction and thus right to left is the negative direction (Fig. 9.19). If symbols m and u represent the mass and initial velocity of the two players, respectively. Subscripts 1 and 2 in these physical quantities refer to the two hockey players. Thus,

m_1 = 60 kg; u_1 = + 5 m s^{-1}; and

m_2 = 55 kg; u_2 = – 6 m s^{-1}.

The total momentum of the two players before the collision

= 60 kg × (+ 5 m s^{-1}) + 55 kg × (– 6 m s^{-1})

= – 30 kg m s^{-1}

If v is the velocity of the two entangled players after the collision, the total momentum then

= $(m_1 + m_2) \times v$

= (60 + 55) kg × v m s^{-1}

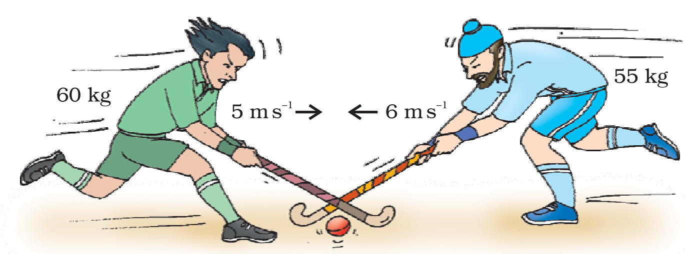
= 115 × v kg m s^{-1}.

Equating the momenta of the system before and after collision, in accordance with the law of conservation of momentum, we get

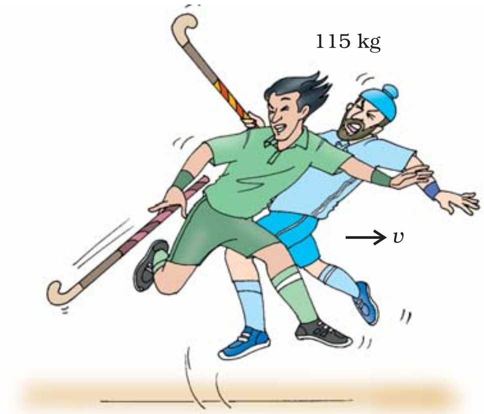
v = – 30/115

= – 0.26 m s^{-1}.

Thus, the two entangled players would move with velocity 0.26 m s^{-1} from right to left, that is, in the direction the second player was moving before the collision.



(a)



(b)

Fig. 9.19: *A collision of two hockey players: (a) before collision and (b) after collision.*

Questions

1. *If action is always equal to the reaction, explain how a horse can pull a cart.*
2. *Explain, why is it difficult for a fireman to hold a hose, which ejects large amounts of water at a high velocity.*
3. *From a rifle of mass 4 kg, a bullet of mass 50 g is fired with an initial velocity of 35 m s^{-1}. Calculate the initial recoil velocity of the rifle.*

4. *Two objects of masses 100 g and 200 g are moving along the same line and direction with velocities of 2 m s^{-1} and 1 m s^{-1}, respectively. They collide and after the collision, the first object moves at a velocity of 1.67 m s^{-1}. Determine the velocity of the second object.*

CONSERVATION LAWS

All conservation laws such as conservation of momentum, energy, angular momentum, charge etc. are considered to be fundamental laws in physics. These are based on observations and experiments. It is important to remember that a conservation law cannot be proved. It can be verified, or disproved, by experiments. An experiment whose result is in conformity with the law verifies or substantiates the law; it does not prove the law. On the other hand, a single experiment whose result goes against the law is enough to disprove it.

The law of conservation of momentum has been deduced from large number of observations and experiments. This law was formulated nearly three centuries ago. It is interesting to note that not a single situation has been realised so far, which contradicts this law. Several experiences of every-day life can be explained on the basis of the law of conservation of momentum.

What you have learnt

- First law of motion: An object continues to be in a state of rest or of uniform motion along a straight line unless acted upon by an unbalanced force.
- The natural tendency of objects to resist a change in their state of rest or of uniform motion is called inertia.
- The mass of an object is a measure of its inertia. Its SI unit is kilogram (kg).
- Force of friction always opposes motion of objects.
- Second law of motion: The rate of change of momentum of an object is proportional to the applied unbalanced force in the direction of the force.
- The SI unit of force is kg m s^{-2}. This is also known as newton and represented by the symbol N. A force of one newton produces an acceleration of 1 m s^{-2} on an object of mass 1 kg.
- The momentum of an object is the product of its mass and velocity and has the same direction as that of the velocity. Its SI unit is kg m s^{-1}.
- Third law of motion: To every action, there is an equal and opposite reaction and they act on two different bodies.
- In an isolated system (where there is no external force), the total momentum remains conserved.

Exercises

1. An object experiences a net zero external unbalanced force. Is it possible for the object to be travelling with a non-zero velocity? If yes, state the conditions that must be placed on the magnitude and direction of the velocity. If no, provide a reason.
2. When a carpet is beaten with a stick, dust comes out of it. Explain.
3. Why is it advised to tie any luggage kept on the roof of a bus with a rope?
4. A batsman hits a cricket ball which then rolls on a level ground. After covering a short distance, the ball comes to rest. The ball slows to a stop because
   (a) the batsman did not hit the ball hard enough.
   (b) velocity is proportional to the force exerted on the ball.
   (c) there is a force on the ball opposing the motion.
   (d) there is no unbalanced force on the ball, so the ball would want to come to rest.
5. A truck starts from rest and rolls down a hill with a constant acceleration. It travels a distance of 400 m in 20 s. Find its acceleration. Find the force acting on it if its mass is 7 tonnes (*Hint*: 1 tonne = 1000 kg.)
6. A stone of 1 kg is thrown with a velocity of 20 m s^{-1} across the frozen surface of a lake and comes to rest after travelling a distance of 50 m. What is the force of friction between the stone and the ice?
7. A 8000 kg engine pulls a train of 5 wagons, each of 2000 kg, along a horizontal track. If the engine exerts a force of 40000 N and the track offers a friction force of 5000 N, then calculate:
   (a) the net accelerating force;
   (b) the acceleration of the train; and
   (c) the force of wagon 1 on wagon 2.
8. An automobile vehicle has a mass of 1500 kg. What must be the force between the vehicle and road if the vehicle is to be stopped with a negative acceleration of 1.7 m s^{-2}?
9. What is the momentum of an object of mass m, moving with a velocity v?
   (a) $(mv)^2$ (b) mv^2 (c) ½ mv^2 (d) mv
10. Using a horizontal force of 200 N, we intend to move a wooden cabinet across a floor at a constant velocity. What is the friction force that will be exerted on the cabinet?
11. Two objects, each of mass 1.5 kg, are moving in the same straight line but in opposite directions. The velocity of each

object is 2.5 m s^{-1} before the collision during which they stick together. What will be the velocity of the combined object after collision?

12. According to the third law of motion when we push on an object, the object pushes back on us with an equal and opposite force. If the object is a massive truck parked along the roadside, it will probably not move. A student justifies this by answering that the two opposite and equal forces cancel each other. Comment on this logic and explain why the truck does not move.
13. A hockey ball of mass 200 g travelling at 10 m s^{-1} is struck by a hockey stick so as to return it along its original path with a velocity at 5 m s^{-1}. Calculate the change of momentum occurred in the motion of the hockey ball by the force applied by the hockey stick.
14. A bullet of mass 10 g travelling horizontally with a velocity of 150 m s^{-1} strikes a stationary wooden block and comes to rest in 0.03 s. Calculate the distance of penetration of the bullet into the block. Also calculate the magnitude of the force exerted by the wooden block on the bullet.
15. An object of mass 1 kg travelling in a straight line with a velocity of 10 m s^{-1} collides with, and sticks to, a stationary wooden block of mass 5 kg. Then they both move off together in the same straight line. Calculate the total momentum just before the impact and just after the impact. Also, calculate the velocity of the combined object.
16. An object of mass 100 kg is accelerated uniformly from a velocity of 5 m s^{-1} to 8 m s^{-1} in 6 s. Calculate the initial and final momentum of the object. Also, find the magnitude of the force exerted on the object.
17. Akhtar, Kiran and Rahul were riding in a motorcar that was moving with a high velocity on an expressway when an insect hit the windshield and got stuck on the windscreen. Akhtar and Kiran started pondering over the situation. Kiran suggested that the insect suffered a greater change in momentum as compared to the change in momentum of the motorcar (because the change in the velocity of the insect was much more than that of the motorcar). Akhtar said that since the motorcar was moving with a larger velocity, it exerted a larger force on the insect. And as a result the insect died. Rahul while putting an entirely new explanation said that both the motorcar and the insect experienced the same force and a change in their momentum. Comment on these suggestions.
18. How much momentum will a dumb-bell of mass 10 kg transfer to the floor if it falls from a height of 80 cm? Take its downward acceleration to be 10 m s^{-2}.

Additional Exercises

A1. The following is the distance-time table of an object in motion:

Time in seconds	Distance in metres
0	0
1	1
2	8
3	27
4	64
5	125
6	216
7	343

(a) What conclusion can you draw about the acceleration? Is it constant, increasing, decreasing, or zero?

(b) What do you infer about the forces acting on the object?

A2. Two persons manage to push a motorcar of mass 1200 kg at a uniform velocity along a level road. The same motorcar can be pushed by three persons to produce an acceleration of 0.2 m s^{-2}. With what force does each person push the motorcar? (Assume that all persons push the motorcar with the same muscular effort.)

A3. A hammer of mass 500 g, moving at 50 m s^{-1}, strikes a nail. The nail stops the hammer in a very short time of 0.01 s. What is the force of the nail on the hammer?

A4. A motorcar of mass 1200 kg is moving along a straight line with a uniform velocity of 90 km/h. Its velocity is slowed down to 18 km/h in 4 s by an unbalanced external force. Calculate the acceleration and change in momentum. Also calculate the magnitude of the force required.

Chapter 10

GRAVITATION

In Chapters 8 and 9, we have learnt about the motion of objects and force as the cause of motion. We have learnt that a force is needed to change the speed or the direction of motion of an object. We always observe that an object dropped from a height falls towards the earth. We know that all the planets go around the Sun. The moon goes around the earth. In all these cases, there must be some force acting on the objects, the planets and on the moon. Isaac Newton could grasp that the same force is responsible for all these. This force is called the gravitational force.

In this chapter we shall learn about gravitation and the universal law of gravitation. We shall discuss the motion of objects under the influence of gravitational force on the earth. We shall study how the weight of a body varies from place to place. We shall also discuss the conditions for objects to float in liquids.

10.1 Gravitation

We know that the moon goes around the earth. An object when thrown upwards, reaches a certain height and then falls downwards. It is said that when Newton was sitting under a tree, an apple fell on him. The fall of the apple made Newton start thinking. He thought that: if the earth can attract an apple, can it not attract the moon? Is the force the same in both cases? He conjectured that the same type of force is responsible in both the cases. He argued that at each point of its orbit, the moon falls towards the earth, instead of going off in a straight line. So, it must be attracted by the earth. But we do not really see the moon falling towards the earth.

Let us try to understand the motion of the moon by recalling activity 8.11.

Activity 10.1

- Take a piece of thread.
- Tie a small stone at one end. Hold the other end of the thread and whirl it round, as shown in Fig. 10.1.
- Note the motion of the stone.
- Release the thread.
- Again, note the direction of motion of the stone.

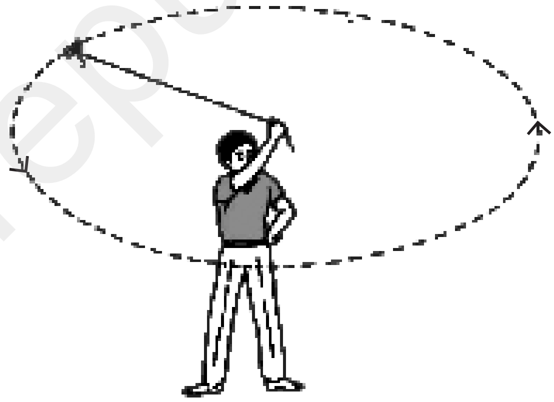
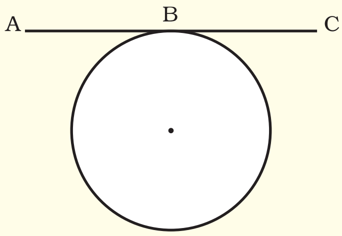


Fig. 10.1: *A stone describing a circular path with a velocity of constant magnitude.*

Before the thread is released, the stone moves in a circular path with a certain speed and changes direction at every point. The change in direction involves change in velocity or acceleration. The force that causes this acceleration and keeps the body moving along the circular path is acting towards the centre. This force is called the centripetal (meaning 'centre-seeking') force. In the absence of this force, the stone flies off along a straight line. This straight line will be a tangent to the circular path.

> **More to know**
>
> **Tangent to a circle**
>
> 
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>
> A straight line that meets the circle at one and only one point is called a tangent to the circle. Straight line ABC is a tangent to the circle at point B.

The motion of the moon around the earth is due to the centripetal force. The centripetal force is provided by the force of attraction of the earth. If there were no such force, the moon would pursue a uniform straight line motion.

It is seen that a falling apple is attracted towards the earth. Does the apple attract the earth? If so, we do not see the earth moving towards an apple. Why?

According to the third law of motion, the apple does attract the earth. But according to the second law of motion, for a given force, acceleration is inversely proportional to the mass of an object [Eq. (9.4)]. The mass of an apple is negligibly small compared to that of the earth. So, we do not see the earth moving towards the apple. Extend the same argument for why the earth does not move towards the moon.

In our solar system, all the planets go around the Sun. By arguing the same way, we can say that there exists a force between the Sun and the planets. From the above facts Newton concluded that not only does the earth attract an apple and the moon, but all objects in the universe attract each other. This force of attraction between objects is called the gravitational force.

10.1.1 Universal Law of Gravitation

Every object in the universe attracts every other object with a force which is proportional to the product of their masses and inversely proportional to the square of the distance between them. The force is along the line joining the centres of two objects.

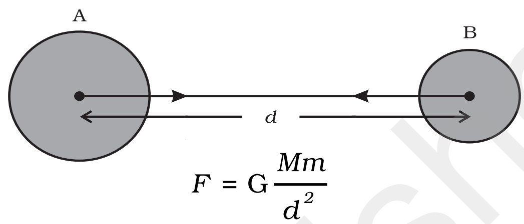


Fig. 10.2: *The gravitational force between two uniform objects is directed along the line joining their centres.*

Let two objects A and B of masses *M* and *m* lie at a distance *d* from each other as shown in Fig. 10.2. Let the force of attraction between two objects be *F*. According to the universal law of gravitation, the force between two objects is directly proportional to the product of their masses. That is,

$$F \quad M \times m \qquad (10.1)$$

And the force between two objects is inversely proportional to the square of the distance between them, that is,

$$F \quad \frac{1}{d^2} \qquad (10.2)$$

Combining Eqs. (10.1) and (10.2), we get

$$F \quad \frac{M \quad m}{d^2} \qquad (10.3)$$

or, $$F = G\frac{M \times m}{d^2} \qquad (10.4)$$

where G is the constant of proportionality and is called the universal gravitation constant. By multiplying crosswise, Eq. (10.4) gives

$$F \times d^2 = G\, M \times m$$

Isaac Newton
(1642 – 1727)

Isaac Newton was born in Woolsthorpe near Grantham, England. He is generally regarded as the most original and influential theorist in the history of science. He was born in a poor farming family. But he was not good at farming. He was sent to study at Cambridge University in 1661. In 1665 a plague broke out in Cambridge and so Newton took a year off. It was during this year that the incident of the apple falling on him is said to have occurred. This incident prompted Newton to explore the possibility of connecting gravity with the force that kept the moon in its orbit. This led him to the universal law of gravitation. It is remarkable that many great scientists before him knew of gravity but failed to realise it.

Newton formulated the well-known laws of motion. He worked on theories of light and colour. He designed an astronomical telescope to carry out astronomical observations. Newton was also a great mathematician. He invented a new branch of mathematics, called calculus. He used it to prove that for objects outside a sphere of uniform density, the sphere behaves as if the whole of its mass is concentrated at its centre. Newton transformed the structure of physical science with his three laws of motion and the universal law of gravitation. As the keystone of the scientific revolution of the seventeenth century, Newton's work combined the contributions of Copernicus, Kepler, Galileo, and others into a new powerful synthesis.

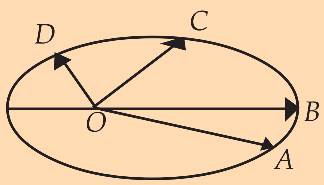
It is remarkable that though the gravitational theory could not be verified at that time, there was hardly any doubt about its correctness. This is because Newton based his theory on sound scientific reasoning and backed it with mathematics. This made the theory simple and elegant. These qualities are now recognised as essential requirements of a good scientific theory.

How did Newton guess the inverse-square rule?

There has always been a great interest in the motion of planets. By the 16th century, a lot of data on the motion of planets had been collected by many astronomers. Based on these data Johannes Kepler derived three laws, which govern the motion of planets. These are called Kepler's laws. These are:

1. The orbit of a planet is an ellipse with the Sun at one of the foci, as shown in the figure given below. In this figure O is the position of the Sun.
2. The line joining the planet and the Sun sweep equal areas in equal intervals of time. Thus, if the time of travel from A to B is the same as that from C to D, then the areas OAB and OCD are equal.
3. The cube of the mean distance of a planet from the Sun is proportional to the square of its orbital period T. Or, r^3/T^2 = constant.

It is important to note that Kepler could not give a theory to explain the motion of planets. It was Newton who showed that the cause of the planetary motion is the gravitational force that the Sun exerts on them. Newton used the third law of Kepler to calculate the gravitational force of attraction. The gravitational force of the earth is weakened by distance. A simple argument goes like this. We can assume that the planetary orbits are circular. Suppose the orbital velocity is v and the radius of the orbit is r. Then the force acting on an orbiting planet is given by $F \propto v^2/r$.



If T denotes the period, then $v = 2\pi r/T$, so that $v^2 \propto r^2/T^2$.

We can rewrite this as $v^2 \propto (1/r) \times (r^3/T^2)$. Since r^3/T^2 is constant by Kepler's third law, we have $v^2 \propto 1/r$. Combining this with $F \propto v^2/r$, we get, $F \propto 1/r^2$.

$$\text{or} \qquad G \quad \frac{F\,d^2}{M \quad m} \qquad (10.5)$$

The SI unit of G can be obtained by substituting the units of force, distance and mass in Eq. (10.5) as N m^2 kg^{-2}.

The value of G was found out by Henry Cavendish (1731 – 1810) by using a sensitive balance. The accepted value of G is 6.673×10^{-11} N m^2 kg^{-2}.

We know that there exists a force of attraction between any two objects. Compute the value of this force between you and your friend sitting closeby. Conclude how you do not experience this force!

More to know

The law is universal in the sense that it is applicable to all bodies, whether the bodies are big or small, whether they are celestial or terrestrial.

Inverse-square

Saying that *F* is inversely proportional to the square of *d* means, for example, that if *d* gets bigger by a factor of 6, *F* becomes $\frac{1}{36}$ times smaller.

Example 10.1 The mass of the earth is 6×10^{24} kg and that of the moon is $7.4 \quad 10^{22}$ kg. If the distance between the earth and the moon is $3.84 10^5$ km, calculate the force exerted by the earth on the moon. G = $6.7 \quad 10^{-11}$ N m^2 kg^{-2}.

Solution:

The mass of the earth, $M = 6 \quad 10^{24}$ kg

The mass of the moon,

$m = 7.4 \quad 10^{22}$ kg

The distance between the earth and the moon,

$$d = 3.84 \quad 10^5 \text{ km}$$
$$= 3.84 \quad 10^5 \quad 1000 \text{ m}$$
$$= 3.84 \quad 10^8 \text{ m}$$
$$G = 6.7 \quad 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$$

From Eq. (10.4), the force exerted by the earth on the moon is

$$F = G\frac{M \times m}{d^2}$$

$$\frac{6.7 \quad 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \quad 6 \quad 10^{24} \text{ kg} \quad 7.4 \quad 10^{22} \text{ kg}}{(3.84 \quad 10^8 \text{ m})^2}$$

$= 2.01 \times 10^{20}$ N.

Thus, the force exerted by the earth on the moon is 2.01×10^{20} N.

Questions

1. *State the universal law of gravitation.*
2. *Write the formula to find the magnitude of the gravitational force between the earth and an object on the surface of the earth.*

10.1.2 Importance of the Universal Law of Gravitation

The universal law of gravitation successfully explained several phenomena which were believed to be unconnected:

(i) the force that binds us to the earth;

(ii) the motion of the moon around the earth;

(iii) the motion of planets around the Sun; and

(iv) the tides due to the moon and the Sun.

10.2 Free Fall

Let us try to understand the meaning of free fall by performing this activity.

Activity 10.2

- Take a stone.
- Throw it upwards.
- It reaches a certain height and then it starts falling down.

We have learnt that the earth attracts objects towards it. This is due to the gravitational force. Whenever objects fall towards the earth under this force alone, we say that the objects are in free fall. Is there any change in the velocity of falling objects? While falling, there is no change in the direction of motion of the objects. But due to the earth's attraction, there will be a change in the magnitude of the velocity. Any change in velocity involves acceleration. Whenever an object falls towards the earth, an acceleration is involved. This acceleration is due to the earth's gravitational force. Therefore, this acceleration is called the acceleration due to the gravitational force of the earth (or acceleration due to gravity). It is denoted by *g*. The unit of *g* is the same as that of acceleration, that is, m s^{-2}.

We know from the second law of motion that force is the product of mass and acceleration. Let the mass of the stone in activity 10.2 be *m*. We already know that there is acceleration involved in falling objects due to the gravitational force and is denoted by *g*. Therefore the magnitude of the gravitational force *F* will be equal to the product of mass and acceleration due to the gravitational force, that is,

$$F = m\,g \qquad (10.6)$$

From Eqs. (10.4) and (10.6) we have

$$m\,g = G\frac{M \quad m}{d^2}$$

or

$$g = G\frac{M}{d^2} \qquad (10.7)$$

where *M* is the mass of the earth, and *d* is the distance between the object and the earth.

Let an object be on or near the surface of the earth. The distance *d* in Eq. (10.7) will be equal to *R*, the radius of the earth. Thus, for objects on or near the surface of the earth,

$$mg = G\frac{M \times m}{R^2} \qquad (10.8)$$

$$g = G\frac{M}{R^2} \qquad (10.9)$$

The earth is not a perfect sphere. As the radius of the earth increases from the poles to the equator, the value of *g* becomes greater at the poles than at the equator. For most calculations, we can take *g* to be more or less constant on or near the earth. But for objects far from the earth, the acceleration due to gravitational force of earth is given by Eq. (10.7).

10.2.1 To calculate the value of *g*

To calculate the value of *g*, we should put the values of G, *M* and *R* in Eq. (10.9), namely, universal gravitational constant, G = 6.7 × 10^{-11} N m^2 kg^{-2}, mass of the earth, *M* = 6 × 10^{24} kg, and radius of the earth, *R* = 6.4 × 10^6 m.

$$g = G\frac{M}{R^2}$$

$$= \frac{6.7 \quad 10^{-11}\,N\,m^2\,kg^{-2} \quad 6 \quad 10^{24}\,kg}{(6.4 \quad 10^6\,m)^2}$$

$$= 9.8\ m\ s^{-2}.$$

Thus, the value of acceleration due to gravity of the earth, *g* = 9.8 m s^{-2}.

10.2.2 Motion of objects under the influence of gravitational force of the earth

Let us do an activity to understand whether all objects hollow or solid, big or small, will fall from a height at the same rate.

Activity 10.3

- Take a sheet of paper and a stone. Drop them simultaneously from the first floor of a building. Observe whether both of them reach the ground simultaneously.
- We see that paper reaches the ground little later than the stone. This happens because of air resistance. The air offers resistance due to friction to the motion of the falling objects. The resistance offered by air to the paper is more than the resistance offered to the stone. If we do the experiment in a glass jar from which air has been sucked out, the paper and the stone would fall at the same rate.

We know that an object experiences acceleration during free fall. From Eq. (10.9), this acceleration experienced by an object is independent of its mass. This means that all objects hollow or solid, big or small, should fall at the same rate. According to a story, Galileo dropped different objects from the top of the Leaning Tower of Pisa in Italy to prove the same.

As g is constant near the earth, all the equations for the uniformly accelerated motion of objects become valid with acceleration a replaced by g (see section 8.5). The equations are:

$$v = u + at \qquad (10.10)$$

$$s = ut + \frac{1}{2}at^2 \qquad (10.11)$$

$$v^2 = u^2 + 2as \qquad (10.12)$$

where u and v are the initial and final velocities and s is the distance covered in time, t.

In applying these equations, we will take acceleration, a to be positive when it is in the direction of the velocity, that is, in the direction of motion. The acceleration, a will be taken as negative when it opposes the motion.

Example 10.2 A car falls off a ledge and drops to the ground in 0.5 s. Let g = 10 m s^{-2} (for simplifying the calculations).

(i) What is its speed on striking the ground?

(ii) What is its average speed during the 0.5 s?

(iii) How high is the ledge from the ground?

Solution:

Time, t = □ second

Initial velocity, u = 0 m s^{-1}

Acceleration due to gravity, g = 10 m s^{-2}

Acceleration of the car, a = + 10 m s^{-2} (downward)

(i) speed $v = a\,t$

v = 10 m s^{-2} × 0.5 s

= 5 m s^{-1}

(ii) average speed $= \frac{u+v}{2}$

= (0 m s^{-1} + 5 m s^{-1})/2

= 2.5 m s^{-1}

(iii) distance travelled, s = □ $a\,t^2$

= □ × 10 m s^{-2} × (0.5 s)^2

= □ × 10 m s^{-2} × 0.25 s^2

= 1.25 m

Thus,

(i) its speed on striking the ground = 5 m s^{-1}

(ii) its average speed during the 0.5 s = 2.5 m s^{-1}

(iii) height of the ledge from the ground = 1.25 m.

Example 10.3 An object is thrown vertically upwards and rises to a height of 10 m. Calculate (i) the velocity with which the object was thrown upwards and (ii) the time taken by the object to reach the highest point.

Solution:

Distance travelled, s = 10 m

Final velocity, v = 0 m s^{-1}

Acceleration due to gravity, g = 9.8 m s^{-2}

Acceleration of the object, a = –9.8 m s^{-2} (upward motion)

(i) $v^2 = u^2 + 2a\,s$

$0 = u^2 + 2 \times (-9.8 \text{ m s}^{-2}) \times 10 \text{ m}$

$-u^2 = -2 \times 9.8 \times 10 \text{ m}^2\text{s}^{-2}$

$u = \sqrt{196}$ m s^{-1}

u = 14 m s^{-1}

(ii) $v = u + a\,t$

0 = 14 m s^{-1} – 9.8 m s^{-2} × t

t = 1.43 s.

Thus,

(i) Initial velocity, u = 14 m s^{-1}, and

(ii) Time taken, t = 1.43 s.

Questions

1. *What do you mean by free fall?*
2. *What do you mean by acceleration due to gravity?*

10.3 Mass

We have learnt in the previous chapter that the mass of an object is the measure of its inertia (section 9.3). We have also learnt that greater the mass, the greater is the inertia. It remains the same whether the object is on the earth, the moon or even in outer space. Thus, the mass of an object is constant and does not change from place to place.

10.4 Weight

We know that the earth attracts every object with a certain force and this force depends on the mass (*m*) of the object and the acceleration due to the gravity (*g*). The weight of an object is the force with which it is attracted towards the earth.

We know that

$$F = m \times a, \qquad (10.13)$$

that is,

$$F = m \times g. \qquad (10.14)$$

The force of attraction of the earth on an object is known as the weight of the object. It is denoted by *W*. Substituting the same in Eq. (10.14), we have

$$W = m \times g \qquad (10.15)$$

As the weight of an object is the force with which it is attracted towards the earth, the SI unit of weight is the same as that of force, that is, newton (N). The weight is a force acting vertically downwards; it has both magnitude and direction.

We have learnt that the value of *g* is constant at a given place. Therefore at a given place, the weight of an object is directly proportional to the mass, say *m*, of the object, that is, $W \quad m$. It is due to this reason that at a given place, we can use the weight of an object as a measure of its mass. The mass of an object remains the same everywhere, that is, on the earth and on any planet whereas its weight depends on its location.

10.4.1 Weight of an Object on the Moon

We have learnt that the weight of an object on the earth is the force with which the earth attracts the object. In the same way, the weight of an object on the moon is the force with which the moon attracts that object. The mass of the moon is less than that of the earth. Due to this the moon exerts lesser force of attraction on objects.

Let the mass of an object be *m*. Let its weight on the moon be W_m. Let the mass of the moon be M_m and its radius be R_m.

By applying the universal law of gravitation, the weight of the object on the moon will be

$$W_m \quad G \frac{M_m \quad m}{R_m^2} \qquad (10.16)$$

Let the weight of the same object on the earth be W_e. The mass of the earth is *M* and its radius is *R*.

Table 10.1

Celestial body	Mass (kg)	Radius (m)
Earth	5.98 10^{24}	6.37 10^{6}
Moon	7.36 10^{22}	1.74 10^{6}

From Eqs. (10.9) and (10.15) we have,

$$W_e \quad G \frac{M \quad m}{R^2} \qquad (10.17)$$

Substituting the values from Table 10.1 in Eqs. (10.16) and (10.17), we get

$$W_m \quad G \frac{7.36 \quad 10^{22}\,\text{kg} \quad m}{1.74 \quad 10^{6}\,\text{m} \quad ^2}$$

$$W_m \quad 2.431 \quad 10^{10}\,G \times m \qquad (10.18a)$$

and $W_e \quad 1.474 \quad 10^{11}\,G \times m$ (10.18b)

Dividing Eq. (10.18a) by Eq. (10.18b), we get

$$\frac{W_m}{W_e} \quad \frac{2.431 \quad 10^{10}}{1.474 \quad 10^{11}}$$

or $$\frac{W_m}{W_e} = 0.165 \approx \frac{1}{6} \qquad (10.19)$$

$$\frac{\text{Weight of the object on the moon}}{\text{Weight of the object on the earth}} = \frac{1}{6}$$

Weight of the object on the moon
= (1/6) × its weight on the earth.

Example 10.4 Mass of an object is 10 kg. What is its weight on the earth?

Solution:

Mass, m = 10 kg

Acceleration due to gravity, $g = 9.8 \text{ m s}^{-2}$

$W = m \times g$

$W = 10 \text{ kg} \times 9.8 \text{ m s}^{-2} = 98 \text{ N}$

Thus, the weight of the object is 98 N.

Example 10.5 An object weighs 10 N when measured on the surface of the earth. What would be its weight when measured on the surface of the moon?

Solution:

We know,

Weight of object on the moon

= (1/6) × its weight on the earth.

That is,

$$W_m = \frac{W_e}{6} = \frac{10}{6} \text{ N}.$$

= 1.67 N.

Thus, the weight of object on the surface of the moon would be 1.67 N.

Questions

1. *What are the differences between the mass of an object and its weight?*
2. *Why is the weight of an object on the moon $\frac{1}{6}^{th}$ its weight on the earth?*

10.5 Thrust and Pressure

Have you ever wondered why a camel can run in a desert easily? Why an army tank weighing more than a thousand tonne rests upon a continuous chain? Why a truck or a motorbus has much wider tyres? Why cutting tools have sharp edges? In order to address these questions and understand the phenomena involved, it helps to introduce the concepts of the net force in a particular direction (thrust) and the force per unit area (pressure) acting on the object concerned.

Let us try to understand the meanings of thrust and pressure by considering the following situations:

Situation 1: You wish to fix a poster on a bulletin board, as shown in Fig 10.3. To do this task you will have to press drawing pins with your thumb. You apply a force on the surface area of the head of the pin. This force is directed perpendicular to the surface area of the board. This force acts on a smaller area at the tip of the pin.

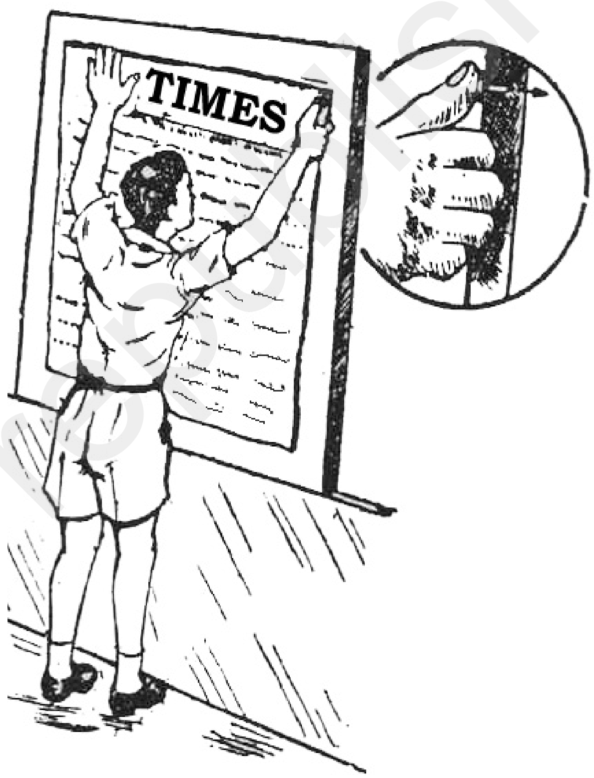


Fig. 10.3: *To fix a poster, drawing pins are pressed with the thumb perpendicular to the board.*

Situation 2: You stand on loose sand. Your feet go deep into the sand. Now, lie down on the sand. You will find that your body will not go that deep in the sand. In both cases the force exerted on the sand is the weight of your body.

You have learnt that weight is the force acting vertically downwards. Here the force is acting perpendicular to the surface of the sand. The force acting on an object perpendicular to the surface is called thrust.

When you stand on loose sand, the force, that is, the weight of your body is acting on an area equal to area of your feet. When you lie down, the same force acts on an area equal to the contact area of your whole body, which is larger than the area of your feet. Thus, the effects of forces of the same magnitude on different areas are different. In the above cases, thrust is the same. But effects are different. Therefore the effect of thrust depends on the area on which it acts.

The effect of thrust on sand is larger while standing than while lying. The thrust on unit area is called pressure. Thus,

$$\text{Pressure} = \frac{\text{thrust}}{\text{area}} \tag{10.20}$$

Substituting the SI unit of thrust and area in Eq. (10.20), we get the SI unit of pressure as N/m^2 or $N\ m^{-2}$.

In honour of scientist Blaise Pascal, the SI unit of pressure is called pascal, denoted as Pa.

Let us consider a numerical example to understand the effects of thrust acting on different areas.

Example 10.6 A block of wood is kept on a tabletop. The mass of wooden block is 5 kg and its dimensions are 40 cm × 20 cm × 10 cm. Find the pressure exerted by the wooden block on the table top if it is made to lie on the table top with its sides of dimensions (a) 20 cm × 10 cm and (b) 40 cm × 20 cm.

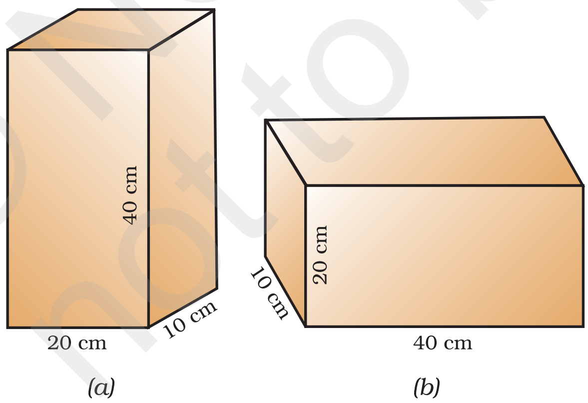


Fig. 10.4

Solution:

The mass of the wooden block = 5 kg

The dimensions

$$= 40\ \text{cm} \times 20\ \text{cm} \times 10\ \text{cm}$$

Here, the weight of the wooden block applies a thrust on the table top.

That is,

$$\begin{aligned}\text{Thrust} = F &= m \times g \\ &= 5\ \text{kg} \times 9.8\ \text{m s}^{-2} \\ &= 49\ \text{N}\end{aligned}$$

$$\begin{aligned}\text{Area of a side} &= \text{length} \times \text{breadth} \\ &= 20\ \text{cm} \times 10\ \text{cm} \\ &= 200\ \text{cm}^2 = 0.02\ \text{m}^2\end{aligned}$$

From Eq. (10.20),

$$\text{Pressure} = \frac{49\text{N}}{0.02\text{m}^2}$$

$$= 2450\ \text{N m}^{-2}.$$

When the block lies on its side of dimensions 40 cm × 20 cm, it exerts the same thrust.

$$\begin{aligned}\text{Area} &= \text{length} \times \text{breadth} \\ &= 40\ \text{cm} \times 20\ \text{cm} \\ &= 800\ \text{cm}^2 = 0.08\ \text{m}^2\end{aligned}$$

From Eq. (10.20),

$$\text{Pressure} = \frac{49\text{N}}{0.08\text{m}^2}$$

$$= 612.5\ \text{N m}^{-2}$$

The pressure exerted by the side 20 cm × 10 cm is 2450 $N\ m^{-2}$ and by the side 40 cm × 20 cm is 612.5 $N\ m^{-2}$.

Thus, the same force acting on a smaller area exerts a larger pressure, and a smaller pressure on a larger area. This is the reason why a nail has a pointed tip, knives have sharp edges and buildings have wide foundations.

10.5.1 Pressure in Fluids

All liquids and gases are fluids. A solid exerts pressure on a surface due to its weight. Similarly, fluids have weight, and they also exert pressure on the base and walls of the container in which they are enclosed. Pressure exerted in any confined mass of fluid is transmitted undiminished in all directions.

10.5.2 Buoyancy

Have you ever had a swim in a pool and felt lighter? Have you ever drawn water from a well and felt that the bucket of water is heavier when it is out of the water? Have you ever wondered why a ship made of iron and steel does not sink in sea water, but while the same amount of iron and steel in the form of a sheet would sink? These questions can be answered by taking buoyancy in consideration. Let us understand the meaning of buoyancy by doing an activity.

Activity 10.4

- Take an empty plastic bottle. Close the mouth of the bottle with an airtight stopper. Put it in a bucket filled with water. You see that the bottle floats.
- Push the bottle into the water. You feel an upward push. Try to push it further down. You will find it difficult to push deeper and deeper. This indicates that water exerts a force on the bottle in the upward direction. The upward force exerted by the water goes on increasing as the bottle is pushed deeper till it is completely immersed.
- Now, release the bottle. It bounces back to the surface.
- Does the force due to the gravitational attraction of the earth act on this bottle? If so, why doesn't the bottle stay immersed in water after it is released? How can you immerse the bottle in water?

The force due to the gravitational attraction of the earth acts on the bottle in the downward direction. So the bottle is pulled downwards. But the water exerts an upward force on the bottle. Thus, the bottle is pushed upwards. We have learnt that weight of an object is the force due to gravitational attraction of the earth. When the bottle is immersed, the upward force exerted by the water on the bottle is greater than its weight. Therefore it rises up when released.

To keep the bottle completely immersed, the upward force on the bottle due to water must be balanced. This can be achieved by an externally applied force acting downwards. This force must at least be equal to the difference between the upward force and the weight of the bottle.

The upward force exerted by the water on the bottle is known as upthrust or buoyant force. In fact, all objects experience a force of buoyancy when they are immersed in a fluid. The magnitude of this buoyant force depends on the density of the fluid.

10.5.3 Why objects float or sink when placed on the surface of water?

Let us do the following activities to arrive at an answer for the above question.

Activity 10.5

- Take a beaker filled with water.
- Take an iron nail and place it on the surface of the water.
- Observe what happens.

The nail sinks. The force due to the gravitational attraction of the earth on the iron nail pulls it downwards. There is an upthrust of water on the nail, which pushes it upwards. But the downward force acting on the nail is greater than the upthrust of water on the nail. So it sinks (Fig. 10.5).

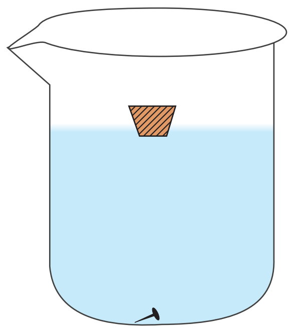


Fig. 10.5: *An iron nail sinks and a cork floats when placed on the surface of water.*

Activity 10.6

- Take a beaker filled with water.
- Take a piece of cork and an iron nail of equal mass.
- Place them on the surface of water.
- Observe what happens.

The cork floats while the nail sinks. This happens because of the difference in their densities. The density of a substance is defined as the mass per unit volume. The density of cork is less than the density of water. This means that the upthrust of water on the cork is greater than the weight of the cork. So it floats (Fig. 10.5).

The density of an iron nail is more than the density of water. This means that the upthrust of water on the iron nail is less than the weight of the nail. So it sinks.

Therefore objects of density less than that of a liquid float on the liquid. The objects of density greater than that of a liquid sink in the liquid.

Questions

1. *Why is it difficult to hold a school bag having a strap made of a thin and strong string?*
2. *What do you mean by buoyancy?*
3. *Why does an object float or sink when placed on the surface of water?*

10.6 Archimedes' Principle

Activity 10.7

- Take a piece of stone and tie it to one end of a rubber string or a spring balance.
- Suspend the stone by holding the balance or the string as shown in Fig. 10.6 (a).
- Note the elongation of the string or the reading on the spring balance due to the weight of the stone.
- Now, slowly dip the stone in the water in a container as shown in Fig. 10.6 (b).

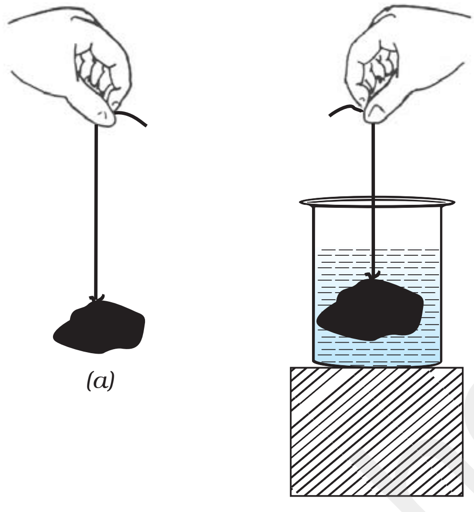


Fig. 10.6: *(a) Observe the elongation of the rubber string due to the weight of a piece of stone suspended from it in air. (b) The elongation decreases as the stone is immersed in water.*

- Observe what happens to elongation of the string or the reading on the balance.

You will find that the elongation of the string or the reading of the balance decreases as the stone is gradually lowered in the water. However, no further change is observed once the stone gets fully immersed in the water. What do you infer from the decrease in the extension of the string or the reading of the spring balance?

We know that the elongation produced in the string or the spring balance is due to the weight of the stone. Since the extension decreases once the stone is lowered in water, it means that some force acts on the stone in upward direction. As a result, the net force on the string decreases and hence the elongation also decreases. As discussed earlier, this upward force exerted by water is known as the force of buoyancy.

What is the magnitude of the buoyant force experienced by a body? Is it the same in all fluids for a given body? Do all bodies in a given fluid experience the same buoyant force? The answer to these questions is contained in Archimedes' principle, stated as follows:

When a body is immersed fully or partially in a fluid, it experiences an upward force that is equal to the weight of the fluid displaced by it.

Now, can you explain why a further decrease in the elongation of the string was not observed in activity 10.7, as the stone was fully immersed in water?


Archimedes

Archimedes was a Greek scientist. He discovered the principle, subsequently named after him, after noticing that the water in a bathtub overflowed when he stepped into it. He ran through the streets shouting "Eureka!", which means "I have got it". This knowledge helped him to determine the purity of the gold in the crown made for the king.

His work in the field of Geometry and Mechanics made him famous. His understanding of levers, pulleys, wheels-and-axle helped the Greek army in its war with Roman army.

Archimedes' principle has many applications. It is used in designing ships and submarines. Lactometers, which are used to determine the purity of a sample of milk and hydrometers used for determining density of liquids, are based on this principle.

Questions

1. *You find your mass to be 42 kg on a weighing machine. Is your mass more or less than 42 kg?*
2. *You have a bag of cotton and an iron bar, each indicating a mass of 100 kg when measured on a weighing machine. In reality, one is heavier than other. Can you say which one is heavier and why?*

10.7 Relative Density

As you know, the density of a substance is defined as mass of a unit volume. The unit of density is kilogram per metre cube (kg m^{-3}). The density of a given substance, under specified conditions, remains the same. Therefore the density of a substance is one of its characteristic properties. It is different for different substances. For example, the density of gold is 19300 kg m^{-3} while that of water is 1000 kg m^{-3}. The density of a given sample of a substance can help us to determine its purity.

It is often convenient to express density of a substance in comparison with that of water. The relative density of a substance is the ratio of its density to that of water:

$$\text{Relative density} = \frac{\text{Density of a substance}}{\text{Density of water}}$$

Since the relative density is a ratio of similar quantities, it has no unit.

Example 10.7 Relative density of silver is 10.8. The density of water is 10^3 kg m^{-3}. What is the density of silver in SI unit?

Solution:

Relative density of silver = 10.8

Relative density

$$= \frac{\text{Density of silver}}{\text{Density of water}}$$

Density of silver

= Relative density of silver

$\times$ density of water

= 10.8×10^3 kg m^{-3}.

What you have learnt

- The law of gravitation states that the force of attraction between any two objects is proportional to the product of their masses and inversely proportional to the square of the distance between them. The law applies to objects anywhere in the universe. Such a law is said to be universal.
- Gravitation is a weak force unless large masses are involved.
- Force of gravitation due to the earth is called gravity.
- The force of gravity decreases with altitude. It also varies on the surface of the earth, decreasing from poles to the equator.
- The weight of a body is the force with which the earth attracts it.
- The weight is equal to the product of mass and acceleration due to gravity.
- The weight may vary from place to place but the mass stays constant.
- All objects experience a force of buoyancy when they are immersed in a fluid.
- Objects having density less than that of the liquid in which they are immersed, float on the surface of the liquid. If the density of the object is more than the density of the liquid in which it is immersed then it sinks in the liquid.

Exercises

1. How does the force of gravitation between two objects change when the distance between them is reduced to half ?
2. Gravitational force acts on all objects in proportion to their masses. Why then, a heavy object does not fall faster than a light object?
3. What is the magnitude of the gravitational force between the earth and a 1 kg object on its surface? (Mass of the earth is 6×10^{24} kg and radius of the earth is 6.4×10^{6} m.)
4. The earth and the moon are attracted to each other by gravitational force. Does the earth attract the moon with a force that is greater or smaller or the same as the force with which the moon attracts the earth? Why?
5. If the moon attracts the earth, why does the earth not move towards the moon?

6. What happens to the force between two objects, if
   (i) the mass of one object is doubled?
   (ii) the distance between the objects is doubled and tripled?
   (iii) the masses of both objects are doubled?
7. What is the importance of universal law of gravitation?
8. What is the acceleration of free fall?
9. What do we call the gravitational force between the earth and an object?
10. Amit buys few grams of gold at the poles as per the instruction of one of his friends. He hands over the same when he meets him at the equator. Will the friend agree with the weight of gold bought? If not, why? [*Hint*: The value of g is greater at the poles than at the equator.]
11. Why will a sheet of paper fall slower than one that is crumpled into a ball?
12. Gravitational force on the surface of the moon is only $\frac{1}{6}$ as strong as gravitational force on the earth. What is the weight in newtons of a 10 kg object on the moon and on the earth?
13. A ball is thrown vertically upwards with a velocity of 49 m/s. Calculate
   (i) the maximum height to which it rises,
   (ii) the total time it takes to return to the surface of the earth.
14. A stone is released from the top of a tower of height 19.6 m. Calculate its final velocity just before touching the ground.
15. A stone is thrown vertically upward with an initial velocity of 40 m/s. Taking $g = 10\ m/s^2$, find the maximum height reached by the stone. What is the net displacement and the total distance covered by the stone?
16. Calculate the force of gravitation between the earth and the Sun, given that the mass of the earth = 6×10^{24} kg and of the Sun = 2×10^{30} kg. The average distance between the two is 1.5×10^{11} m.
17. A stone is allowed to fall from the top of a tower 100 m high and at the same time another stone is projected vertically upwards from the ground with a velocity of 25 m/s. Calculate when and where the two stones will meet.
18. A ball thrown up vertically returns to the thrower after 6 s. Find
   (a) the velocity with which it was thrown up,
   (b) the maximum height it reaches, and
   (c) its position after 4 s.

19. In what direction does the buoyant force on an object immersed in a liquid act?
20. Why does a block of plastic released under water come up to the surface of water?
21. The volume of 50 g of a substance is 20 cm^3. If the density of water is 1 g cm^{-3}, will the substance float or sink?
22. The volume of a 500 g sealed packet is 350 cm^3. Will the packet float or sink in water if the density of water is 1 g cm^{-3}? What will be the mass of the water displaced by this packet?

Chapter 11

Work and Energy

In the previous few chapters we have talked about ways of describing the motion of objects, the cause of motion and gravitation. Another concept that helps us understand and interpret many natural phenomena is 'work'. Closely related to work are energy and power. In this chapter we shall study these concepts.

All living beings need food. Living beings have to perform several basic activities to survive. We call such activities 'life processes'. The energy for these processes comes from food. We need energy for other activities like playing, singing, reading, writing, thinking, jumping, cycling and running. Activities that are strenuous require more energy.

Animals too get engaged in activities. For example, they may jump and run. They have to fight, move away from enemies, find food or find a safe place to live. Also, we engage some animals to lift weights, carry loads, pull carts or plough fields. All such activities require energy.

Think of machines. List the machines that you have come across. What do they need for their working? Why do some engines require fuel like petrol and diesel? Why do living beings and machines need energy?

11.1 Work

What is work? There is a difference in the way we use the term 'work' in day-to-day life and the way we use it in science. To make this point clear let us consider a few examples.

11.1.1 Not much 'work' in spite of working hard!

Kamali is preparing for examinations. She spends lot of time in studies. She reads books, draws diagrams, organises her thoughts, collects question papers, attends classes, discusses problems with her friends, and performs experiments. She expends a lot of energy on these activities. In common parlance, she is 'working hard'. All this 'hard work' may involve very little 'work' if we go by the scientific definition of work.

You are working hard to push a huge rock. Let us say the rock does not move despite all the effort. You get completely exhausted. However, you have not done any work on the rock as there is no displacement of the rock.

You stand still for a few minutes with a heavy load on your head. You get tired. You have exerted yourself and have spent quite a bit of your energy. Are you doing work on the load? The way we understand the term 'work' in science, work is not done.

You climb up the steps of a staircase and reach the second floor of a building just to see the landscape from there. You may even climb up a tall tree. If we apply the scientific definition, these activities involve a lot of work.

In day-to-day life, we consider any useful physical or mental labour as work. Activities like playing in a field, talking with friends, humming a tune, watching a movie, attending a function are sometimes not considered to be work. What constitutes 'work' depends on the way we define it. We use and define the term work differently in science. To understand this let us do the following activities:

Activity 11.1

- We have discussed in the above paragraphs a number of activities which we normally consider to be work

in day-to-day life. For each of these activities, ask the following questions and answer them:
(i) What is the work being done on?
(ii) What is happening to the object?
(iii) Who (what) is doing the work?

11.1.2 Scientific conception of work

To understand the way we view work and define work from the point of view of science, let us consider some situations:

Push a pebble lying on a surface. The pebble moves through a distance. You exerted a force on the pebble and the pebble got displaced. In this situation work is done.

A girl pulls a trolley and the trolley moves through a distance. The girl has exerted a force on the trolley and it is displaced. Therefore, work is done.

Lift a book through a height. To do this you must apply a force. The book rises up. There is a force applied on the book and the book has moved. Hence, work is done.

A closer look at the above situations reveals that two conditions need to be satisfied for work to be done: (i) a force should act on an object, and (ii) the object must be displaced.

If any one of the above conditions does not exist, work is not done. This is the way we view work in science.

A bullock is pulling a cart. The cart moves. There is a force on the cart and the cart has moved. Do you think that work is done in this situation?

Activity 11.2

- Think of some situations from your daily life involving work.
- List them.
- Discuss with your friends whether work is being done in each situation.
- Try to reason out your response.
- If work is done, which is the force acting on the object?
- What is the object on which the work is done?
- What happens to the object on which work is done?

Activity 11.3

- Think of situations when the object is not displaced in spite of a force acting on it.
- Also think of situations when an object gets displaced in the absence of a force acting on it.
- List all the situations that you can think of for each.
- Discuss with your friends whether work is done in these situations.

11.1.3 Work done by a constant force

How is work defined in science? To understand this, we shall first consider the case when the force is acting in the direction of displacement.

Let a constant force, F act on an object. Let the object be displaced through a distance, s in the direction of the force (Fig. 11.1). Let W be the work done. We define work to be equal to the product of the force and displacement.

Work done = force × displacement

$$W = F\,s \qquad (11.1)$$

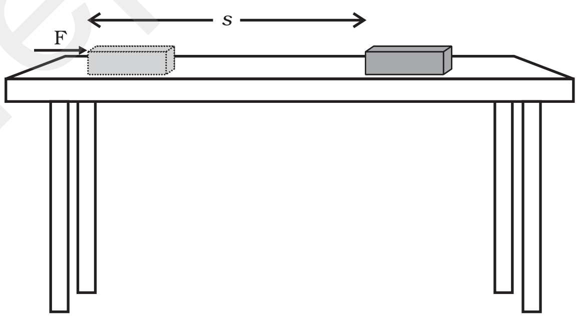


Fig. 11.1

Thus, work done by a force acting on an object is equal to the magnitude of the force multiplied by the distance moved in the direction of the force. Work has only magnitude and no direction.

In Eq. (11.1), if F = 1 N and s = 1 m then the work done by the force will be 1 N m. Here the unit of work is newton metre (N m) or joule (J). Thus 1 J is the amount of work done on an object when a force of 1 N displaces it by 1 m along the line of action of the force.

Look at Eq. (11.1) carefully. What is the work done when the force on the object is zero? What would be the work done when the displacement of the object is zero? Refer to the conditions that are to be satisfied to say that work is done.

Example 11.1 A force of 5 N is acting on an object. The object is displaced through 2 m in the direction of the force (Fig. 11.2). If the force acts on the object all through the displacement, then work done is 5 N × 2 m = 10 N m or 10 J.

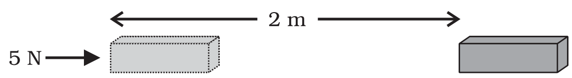


Fig. 11.2

Question

1. *A force of 7 N acts on an object. The displacement is, say 8 m, in the direction of the force (Fig. 11.3). Let us take it that the force acts on the object through the displacement. What is the work done in this case?*

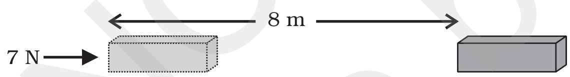


Fig. 11.3

Consider another situation in which the force and the displacement are in the same direction: a baby pulling a toy car parallel to the ground, as shown in Fig. 11.4. The baby has exerted a force in the direction of displacement of the car. In this situation, the work done will be equal to the product of the force and displacement. In such situations, the work done by the force is taken as positive.

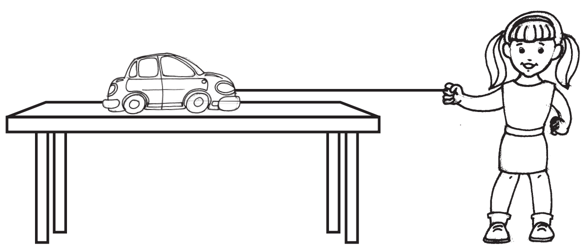


Fig. 11.4

Consider a situation in which an object is moving with a uniform velocity along a particular direction. Now a retarding force, F, is applied in the opposite direction. That is, the angle between the two directions is 180°. Let the object stop after a displacement *s*. In such a situation, the work done by the force, *F* is taken as negative and denoted by the minus sign. The work done by the force is $F \times (-s)$ or $(-F \times s)$.

It is clear from the above discussion that the work done by a force can be either positive or negative. To understand this, let us do the following activity:

Activity 11.4

- Lift an object up. Work is done by the force exerted by you on the object. The object moves upwards. The force you exerted is in the direction of displacement. However, there is the force of gravity acting on the object.
- Which one of these forces is doing positive work?
- Which one is doing negative work?
- Give reasons.

Work done is negative when the force acts opposite to the direction of displacement. Work done is positive when the force is in the direction of displacement.

Example 11.2 A porter lifts a luggage of 15 kg from the ground and puts it on his head 1.5 m above the ground. Calculate the work done by him on the luggage.

Solution:

Mass of luggage, m = 15 kg and displacement, s = 1.5 m.

Work done, $W = F \times s = mg \times s$
$= 15 \text{ kg} \times 10 \text{ m s}^{-2} \times 1.5 \text{ m}$
$= 225 \text{ kg m s}^{-2} \text{ m}$
$= 225 \text{ N m} = 225 \text{ J}$

Work done is 225 J.

Questions

1. *When do we say that work is done?*
2. *Write an expression for the work done when a force is acting on an object in the direction of its displacement.*
3. *Define 1 J of work.*
4. *A pair of bullocks exerts a force of 140 N on a plough. The field being ploughed is 15 m long. How much work is done in ploughing the length of the field?*

11.2 Energy

Life is impossible without energy. The demand for energy is ever increasing. Where do we get energy from? The Sun is the biggest natural source of energy to us. Many of our energy sources are derived from the Sun. We can also get energy from the nuclei of atoms, the interior of the earth, and the tides. Can you think of other sources of energy?

Activity 11.5

- A few sources of energy are listed above. There are many other sources of energy. List them.
- Discuss in small groups how certain sources of energy are due to the Sun.
- Are there sources of energy which are not due to the Sun?

The word energy is very often used in our daily life, but in science we give it a definite and precise meaning. Let us consider the following examples: when a fast moving cricket ball hits a stationary wicket, the wicket is thrown away. Similarly, an object when raised to a certain height gets the capability to do work. You must have seen that when a raised hammer falls on a nail placed on a piece of wood, it drives the nail into the wood. We have also observed children winding a toy (such as a toy car) and when the toy is placed on the floor, it starts moving. When a balloon is filled with air and we press it we notice a change in its shape. As long as we press it gently, it can come back to its original shape when the force is withdrawn. However, if we press the balloon hard, it can even explode producing a blasting sound. In all these examples, the objects acquire, through different means, the capability of doing work. An object having a capability to do work is said to possess energy. The object which does the work loses energy and the object on which the work is done gains energy.

How does an object with energy do work? An object that possesses energy can exert a force on another object. When this happens, energy is transferred from the former to the latter. The second object may move as it receives energy and therefore do some work. Thus, the first object had a capacity to do work. This implies that any object that possesses energy can do work.

The energy possessed by an object is thus measured in terms of its capacity of doing work. The unit of energy is, therefore, the same as that of work, that is, joule (J). 1 J is the energy required to do 1 joule of work. Sometimes a larger unit of energy called kilo joule (kJ) is used. 1 kJ equals 1000 J.

11.2.1 Forms of Energy

Luckily the world we live in provides energy in many different forms. The various forms include mechanical energy (potential energy + kinetic energy), heat energy, chemical energy, electrical energy and light energy.

> **Think it over !**
>
> How do you know that some entity is a form of energy? Discuss with your friends and teachers.

James Prescott Joule (1818 – 1889)

James Prescott Joule was an outstanding British physicist. He is best known for his research in electricity and thermodynamics. Amongst other things, he formulated a law for the heating effect of electric current. He also verified experimentally the law of conservation of energy and discovered the value of the mechanical equivalent of heat. The unit of energy and work called joule, is named after him.

11.2.2 KINETIC ENERGY

Activity ______________ 11.6

- Take a heavy ball. Drop it on a thick bed of sand. A wet bed of sand would be better. Drop the ball on the sand bed from height of about 25 cm. The ball creates a depression.
- Repeat this activity from heights of 50 cm, 1m and 1.5 m.
- Ensure that all the depressions are distinctly visible.
- Mark the depressions to indicate the height from which the ball was dropped.
- Compare their depths.
- Which one of them is deepest?
- Which one is shallowest? Why?
- What has caused the ball to make a deeper dent?
- Discuss and analyse.

Activity ______________ 11.7

- Set up the apparatus as shown in Fig. 11.5.
- Place a wooden block of known mass in front of the trolley at a convenient fixed distance.
- Place a known mass on the pan so that the trolley starts moving.

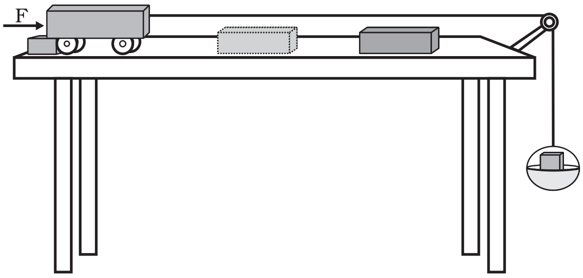


Fig. 11.5

- The trolley moves forward and hits the wooden block.
- Fix a stop on the table in such a manner that the trolley stops after hitting the block. The block gets displaced.
- Note down the displacement of the block. This means work is done on the block by the trolley as the block has gained energy.
- From where does this energy come?
- Repeat this activity by increasing the mass on the pan. In which case is the displacement more?
- In which case is the work done more?
- In this activity, the moving trolley does work and hence it possesses energy.

A moving object can do work. An object moving faster can do more work than an identical object moving relatively slow. A moving bullet, blowing wind, a rotating wheel, a speeding stone can do work. How does a bullet pierce the target? How does the wind move the blades of a windmill? Objects in motion possess energy. We call this energy kinetic energy.

A falling coconut, a speeding car, a rolling stone, a flying aircraft, flowing water, blowing wind, a running athlete etc. possess kinetic energy. In short, kinetic energy is the energy possessed by an object due to its motion. The kinetic energy of an object increases with its speed.

How much energy is possessed by a moving body by virtue of its motion? By definition, we say that the kinetic energy of a body moving with a certain velocity is equal to the work done on it to make it acquire that velocity.

Let us now express the kinetic energy of an object in the form of an equation. Consider an object of mass, m moving with a uniform velocity, u. Let it now be displaced through a distance s when a constant force, F acts on it in the direction of its displacement. From Eq. (11.1), the work done, W is $F\,s$. The work done on the object will cause a change in its velocity. Let its velocity change from u to v. Let a be the acceleration produced.

In section 8.5, we studied three equations of motion. The relation connecting the initial velocity (u) and final velocity (v) of an object moving with a uniform acceleration a, and the displacement, s is

$$v^2 - u^2 = 2a\,s \qquad (8.7)$$

This gives

$$s = \frac{v^2 - u^2}{2a} \qquad (11.2)$$

From section 9.4, we know $F = m\,a$. Thus, using (Eq. 11.2) in Eq. (11.1), we can write the work done by the force, F as

$$W = m\,a\,\frac{v^2 - u^2}{2a}$$

or

$$W = \frac{1}{2}m\left(v^2 - u^2\right) \qquad (11.3)$$

If the object is starting from its stationary position, that is, $u = 0$, then

$$W = \frac{1}{2}m\,v^2 \qquad (11.4)$$

It is clear that the work done is equal to the change in the kinetic energy of an object.

If $u = 0$, the work done will be $\frac{1}{2}m\,v^2$.

Thus, the kinetic energy possessed by an object of mass, m and moving with a uniform velocity, v is

$$E_k = \frac{1}{2}m\,v^2 \qquad (11.5)$$

Example 11.3 An object of mass 15 kg is moving with a uniform velocity of 4 m s^{-1}. What is the kinetic energy possessed by the object?

Solution:

Mass of the object, m = 15 kg, velocity of the object, v = 4 m s^{-1}.
From Eq. (11.5),

$$E_k = \frac{1}{2}m\,v^2$$

$$= \frac{1}{2} \times 15 \text{ kg} \times 4 \text{ m s}^{-1} \times 4 \text{ m s}^{-1}$$

$$= 120 \text{ J}$$

The kinetic energy of the object is 120 J.

Example 11.4 What is the work to be done to increase the velocity of a car from 30 km h^{-1} to 60 km h^{-1} if the mass of the car is 1500 kg?

Solution:

Mass of the car, m =1500 kg,
initial velocity of car, u = 30 km h^{-1}

$$= \frac{30 \times 1000 \text{ m}}{60 \times 60 \text{ s}}$$

$$= 8.33 \text{ m s}^{-1}.$$

Similarly, the final velocity of the car,

$$v = 60 \text{ km h}^{-1}$$
$$= 16.67 \text{ m s}^{-1}.$$

Therefore, the initial kinetic energy of the car,

$$E_{ki} = \frac{1}{2}m\,u^2$$

$$= \frac{1}{2} \times 1500 \text{ kg} \times (8.33 \text{ m s}^{-1})^2$$

$$= 52041.68 \text{ J}.$$

The final kinetic energy of the car,

$$E_{kf} = \frac{1}{2} \times 1500 \text{ kg} \times (16.67 \text{ m s}^{-1})^2$$

$$= 208416.68 \text{ J}.$$

Thus, the work done = Change in kinetic energy

$$= E_{kf} - E_{ki}$$

$$= 156375 \text{ J}.$$

Questions

1. *What is the kinetic energy of an object?*
2. *Write an expression for the kinetic energy of an object.*
3. *The kinetic energy of an object of mass, m moving with a velocity of 5 m s^{-1} is 25 J. What will be its kinetic energy when its velocity is doubled? What will be its kinetic energy when its velocity is increased three times?*

11.2.3 Potential Energy

Activity 11.8

- Take a rubber band.
- Hold it at one end and pull from the other. The band stretches.
- Release the band at one of the ends.
- What happens?
- The band will tend to regain its original length. Obviously the band had acquired energy in its stretched position.
- How did it acquire energy when stretched?

Activity 11.9

- Take a slinky as shown below.
- Ask a friend to hold one of its ends. You hold the other end and move away from your friend. Now you release the slinky.

- What happened?
- How did the slinky acquire energy when stretched?
- Would the slinky acquire energy when it is compressed?

Activity 11.10

- Take a toy car. Wind it using its key.
- Place the car on the ground.
- Did it move?
- From where did it acquire energy?
- Does the energy acquired depend on the number of windings?
- How can you test this?

Activity 11.11

- Lift an object through a certain height. The object can now do work. It begins to fall when released.
- This implies that it has acquired some energy. If raised to a greater height it can do more work and hence possesses more energy.
- From where did it get the energy? Think and discuss.

In the above situations, the energy gets stored due to the work done on the object. The energy transferred to an object is stored as potential energy if it is not used to cause a change in the velocity or speed of the object.

You transfer energy when you stretch a rubber band. The energy transferred to the band is its potential energy. You do work while winding the key of a toy car. The energy transferred to the spring inside is stored as potential energy. The potential energy possessed by the object is the energy present in it by virtue of its position or configuration.

Activity 11.12

- Take a bamboo stick and make a bow as shown in Fig. 11.6.
- Place an arrow made of a light stick on it with one end supported by the stretched string.
- Now stretch the string and release the arrow.
- Notice the arrow flying off the bow. Notice the change in the shape of the bow.
- The potential energy stored in the bow due to the change of shape is thus used in the form of kinetic energy in throwing off the arrow.

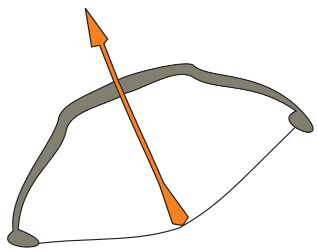


Fig.11.6: *An arrow and the stretched string on the bow.*

11.2.4 Potential energy of an object at a height

An object increases its energy when raised through a height. This is because work is done on it against gravity while it is being raised. The energy present in such an object is the gravitational potential energy.

The gravitational potential energy of an object at a point above the ground is defined as the work done in raising it from the ground to that point against gravity.

It is easy to arrive at an expression for the gravitational potential energy of an object at a height.

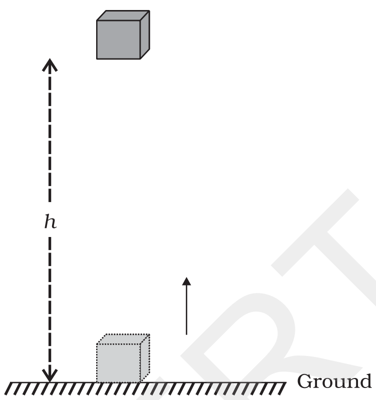


Fig. 11.7

Consider an object of mass, *m*. Let it be raised through a height, *h* from the ground. A force is required to do this. The minimum force required to raise the object is equal to the weight of the object, *mg*. The object gains energy equal to the work done on it. Let the work done on the object against gravity be *W*. That is,

work done, W = force × displacement
= $mg \times h$
= mgh

Since work done on the object is equal to *mgh*, an energy equal to *mgh* units is gained by the object. This is the potential energy (E_p) of the object.

$$E_p = mgh \qquad (11.7)$$

More to know

The potential energy of an object at a height depends on the ground level or the zero level you choose. An object in a given position can have a certain potential energy with respect to one level and a different value of potential energy with respect to another level.

It is useful to note that the work done by gravity depends on the difference in vertical heights of the initial and final positions of the object and not on the path along which the object is moved. Fig. 11.8 shows a case where a block is raised from position A to B by taking two different paths. Let the height AB = *h*. In both the situations the work done on the object is *mgh*.

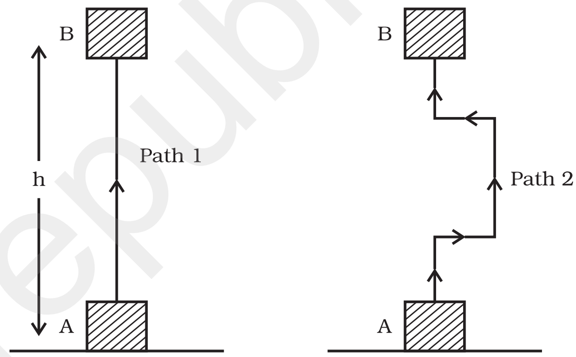


Fig. 11.8

Example 11.5 Find the energy possessed by an object of mass 10 kg when it is at a height of 6 m above the ground. Given, g = 9.8 m s^{-2}.

Solution:

Mass of the object, m = 10 kg, displacement (height), h = 6 m, and acceleration due to gravity, g = 9.8 m s^{-2}.
From Eq. (11.6),
Potential energy = mgh
= 10 kg × 9.8 m s^{-2} × 6 m
= 588 J.
The potential energy is 588 J.

Example 11.6 An object of mass 12 kg is at a certain height above the ground. If the potential energy of the object is 480 J, find the height at which the object is with respect to the ground. Given, $g = 10 \text{ m s}^{-2}$.

Solution:

Mass of the object, $m = 12$ kg,
potential energy, $E_p = 480$ J.

$$E_p = mgh$$
$$480 \text{ J} = 12 \text{ kg} \times 10 \text{ m s}^{-2} \times h$$
$$h = \frac{480 \text{ J}}{120 \text{ kg m s}^{-2}} = 4 \text{ m.}$$

The object is at the height of 4 m.

11.2.5 Are various energy forms interconvertible?

Can we convert energy from one form to another? We find in nature a number of instances of conversion of energy from one form to another.

Activity 11.13

- Sit in small groups.
- Discuss the various ways of energy conversion in nature.
- Discuss following questions in your group:
  (a) How do green plants produce food?
  (b) Where do they get their energy from?
  (c) Why does the air move from place to place?
  (d) How are fuels, such as coal and petroleum formed?
  (e) What kinds of energy conversions sustain the water cycle?

Activity 11.14

- Many of the human activities and the gadgets we use involve conversion of energy from one form to another.
- Make a list of such activities and gadgets.
- Identify in each activity/gadget the kind of energy conversion that takes place.

11.2.6 Law of conservation of energy

In activities 11.13 and 11.14, we learnt that the form of energy can be changed from one form to another. What happens to the total energy of a system during or after the process? Whenever energy gets transformed, the total energy remains unchanged. This is the law of conservation of energy. According to this law, energy can only be converted from one form to another; it can neither be created or destroyed. The total energy before and after the transformation remains the same. The law of conservation of energy is valid in all situations and for all kinds of transformations.

Consider a simple example. Let an object of mass, m be made to fall freely from a height, h. At the start, the potential energy is mgh and kinetic energy is zero. Why is the kinetic energy zero? It is zero because its velocity is zero. The total energy of the object is thus mgh. As it falls, its potential energy will change into kinetic energy. If v is the velocity of the object at a given instant, the kinetic energy would be □mv^2. As the fall of the object continues, the potential energy would decrease while the kinetic energy would increase. When the object is about to reach the ground, $h = 0$ and v will be the highest. Therefore, the kinetic energy would be the largest and potential energy the least. However, the sum of the potential energy and kinetic energy of the object would be the same at all points. That is,
potential energy + kinetic energy = constant

or

$$mgh + \frac{1}{2} mv^2 = \text{constant.} \qquad (11.7)$$

The sum of kinetic energy and potential energy of an object is its total mechanical energy.

We find that during the free fall of the object, the decrease in potential energy, at any point in its path, appears as an equal amount of increase in kinetic energy. (Here the effect of air resistance on the motion of the object has been ignored.) There is thus a continual transformation of gravitational potential energy into kinetic energy.

Activity 11.15

- An object of mass 20 kg is dropped from a height of 4 m. Fill in the blanks in the following table by computing the potential energy and kinetic energy in each case.

Height at which object is located m	Potential energy ($E_p = mgh$) J	Kinetic energy ($E_k = mv^2/2$) J	$E_p + E_k$ J
4			
3			
2			
1			
Just above the ground			

- For simplifying the calculations, take the value of g as 10 m s^{-2}.

Think it over !

What would have happened if nature had not allowed the transformation of energy? There is a view that life could not have been possible without transformation of energy. Do you agree with this?

11.3 Rate of Doing Work

Do all of us work at the same rate? Do machines consume or transfer energy at the same rate? Agents that transfer energy do work at different rates. Let us understand this from the following activity:

Activity 11.16

- Consider two children, say A and B. Let us say they weigh the same. Both start climbing up a rope separately. Both reach a height of 8 m. Let us say A takes 15 s while B takes 20 s to accomplish the task.
- What is the work done by each?
- The work done is the same. However, A has taken less time than B to do the work.
- Who has done more work in a given time, say in 1 s?

A stronger person may do certain work in relatively less time. A more powerful vehicle would complete a journey in a shorter time than a less powerful one. We talk of the power of machines like motorbikes and motorcars. The speed with which these vehicles change energy or do work is a basis for their classification. Power measures the speed of work done, that is, how fast or slow work is done. Power is defined as the rate of doing work or the rate of transfer of energy. If an agent does a work W in time t, then power is given by:

Power = work/time

or $$P = \frac{W}{t} \quad (11.8)$$

The unit of power is watt [in honour of James Watt (1736 – 1819)] having the symbol W. 1 watt is the power of an agent, which does work at the rate of 1 joule per second. We can also say that power is 1 W when the rate of consumption of energy is 1 J s^{-1}.

1 watt = 1 joule/second or 1 W = 1 J s^{-1}.

We express larger rates of energy transfer in kilowatts (kW).

1 kilowatt = 1000 watts
1 kW = 1000 W
1 kW = 1000 J s^{-1}.

The power of an agent may vary with time. This means that the agent may be doing work at different rates at different intervals of time. Therefore the concept of average power is useful. We obtain average power by dividing the total energy consumed by the total time taken.

Example 11.7 Two girls, each of weight 400 N climb up a rope through a height of 8 m. We name one of the girls A and the other B. Girl A takes 20 s while B takes 50 s to accomplish this task. What is the power expended by each girl?

Solution:

(i) Power expended by girl A:
Weight of the girl, mg = 400 N
Displacement (height), h = 8 m

Time taken, $t = 20$ s
From Eq. (11.8),

Power, P = Work done/time taken

$$= \frac{mgh}{t}$$

$$= \frac{400 \text{ N} \times 8 \text{ m}}{20 \text{s}}$$

$$= 160 \text{ W}.$$

(ii) Power expended by girl B:
Weight of the girl, $mg = 400$ N
Displacement (height), $h = 8$ m
Time taken, $t = 50$ s

$$\text{Power, } P = \frac{mgh}{t}$$

$$= \frac{400 \text{ N} \times 8 \text{ m}}{50 \text{ s}}$$

$$= 64 \text{ W}.$$

Power expended by girl A is 160 W.
Power expended by girl B is 64 W.

Example 11.8 A boy of mass 50 kg runs up a staircase of 45 steps in 9 s. If the height of each step is 15 cm, find his power. Take $g = 10 \text{ m s}^{-2}$.

Solution:

Weight of the boy,
$mg = 50 \text{ kg} \times 10 \text{ m s}^{-2} = 500$ N
Height of the staircase,
$h = 45 \times 15/100 \text{ m} = 6.75$ m
Time taken to climb, $t = 9$ s
From Eq. (11.8),
power, P = Work done/time taken

$$= \frac{mgh}{t}$$

$$= \frac{500 \text{ N} \times 6.75 \text{ m}}{9 \text{s}}$$

$$= 375 \text{ W}.$$

Power is 375 W.

Questions

1. *What is power?*
2. *Define 1 watt of power.*
3. *A lamp consumes 1000 J of electrical energy in 10 s. What is its power?*
4. *Define average power.*

11.3.1 Commercial Unit of Energy

The unit joule is too small and hence is inconvenient to express large quantities of energy. We use a bigger unit of energy called kilowatt hour (kW h).

What is 1 kW h? Let us say we have a machine that uses 1000 J of energy every second. If this machine is used continuously for one hour, it will consume 1 kW h of energy. Thus, 1 kW h is the energy used in one hour at the rate of 1000 J s^{-1} (or 1 kW).

$$1 \text{ kW h} = 1 \text{ kW} \times 1 \text{ h}$$
$$= 1000 \text{ W} \times 3600 \text{ s}$$
$$= 3600000 \text{ J}$$
$$1 \text{ kW h} = 3.6 \times 10^6 \text{ J}.$$

The energy used in households, industries and commercial establishments are usually expressed in kilowatt hour. For example, electrical energy used during a month is expressed in terms of 'units'. Here, 1 'unit' means 1 kilowatt hour.

Example 11.9 An electric bulb of 60 W is used for 6 h per day. Calculate the 'units' of energy consumed in one day by the bulb.

Solution:

Power of electric bulb = 60 W
= 0.06 kW.
Time used, t = 6 h
Energy = power × time taken
= 0.06 kW × 6 h
= 0.36 kW h
= 0.36 'units'.

The energy consumed by the bulb is 0.36 'units'.

Activity 11.17

- Take a close look at the electric meter installed in your house. Observe its features closely.
- Take the readings of the meter each day at 6.30 am and 6.30 pm.
- How many 'units' are consumed during day time?
- How many 'units' are used during night?
- Do this activity for about a week.
- Tabulate your observations.
- Draw inferences from the data.
- Compare your observations with the details given in the monthly electricity bill.

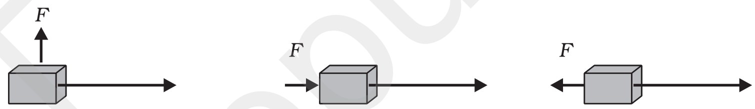
What you have learnt

- Work done on an object is defined as the magnitude of the force multiplied by the distance moved by the object in the direction of the applied force. The unit of work is joule: 1 joule = 1 newton × 1 metre.
- Work done on an object by a force would be zero if the displacement of the object is zero.
- An object having capability to do work is said to possess energy. Energy has the same unit as that of work.
- An object in motion possesses what is known as the kinetic energy of the object. An object of mass, m moving with velocity v has a kinetic energy of $\frac{1}{2}mv^2$.
- The energy possessed by a body due to its change in position or shape is called the potential energy. The gravitational potential energy of an object of mass, m raised through a height, h from the earth's surface is given by $m\,g\,h$.
- According to the law of conservation of energy, energy can only be transformed from one form to another; it can neither be created nor destroyed. The total energy before and after the transformation always remains constant.
- Energy exists in nature in several forms such as kinetic energy, potential energy, heat energy, chemical energy etc. The sum of the kinetic and potential energies of an object is called its mechanical energy.
- Power is defined as the rate of doing work. The SI unit of power is watt. 1 W = 1 J/s.
- The energy used in one hour at the rate of 1kW is called 1 kW h.

Exercises

1. Look at the activities listed below. Reason out whether or not work is done in the light of your understanding of the term 'work'.
   - Suma is swimming in a pond.
   - A donkey is carrying a load on its back.
   - A wind-mill is lifting water from a well.
   - A green plant is carrying out photosynthesis.
   - An engine is pulling a train.
   - Food grains are getting dried in the sun.
   - A sailboat is moving due to wind energy.
2. An object thrown at a certain angle to the ground moves in a curved path and falls back to the ground. The initial and the final points of the path of the object lie on the same horizontal line. What is the work done by the force of gravity on the object?
3. A battery lights a bulb. Describe the energy changes involved in the process.
4. Certain force acting on a 20 kg mass changes its velocity from 5 m s^{-1} to 2 m s^{-1}. Calculate the work done by the force.
5. A mass of 10 kg is at a point A on a table. It is moved to a point B. If the line joining A and B is horizontal, what is the work done on the object by the gravitational force? Explain your answer.
6. The potential energy of a freely falling object decreases progressively. Does this violate the law of conservation of energy? Why?
7. What are the various energy transformations that occur when you are riding a bicycle?
8. Does the transfer of energy take place when you push a huge rock with all your might and fail to move it? Where is the energy you spend going?
9. A certain household has consumed 250 units of energy during a month. How much energy is this in joules?
10. An object of mass 40 kg is raised to a height of 5 m above the ground. What is its potential energy? If the object is allowed to fall, find its kinetic energy when it is half-way down.
11. What is the work done by the force of gravity on a satellite moving round the earth? Justify your answer.
12. Can there be displacement of an object in the absence of any force acting on it? Think. Discuss this question with your friends and teacher.

13. A person holds a bundle of hay over his head for 30 minutes and gets tired. Has he done some work or not? Justify your answer.
14. An electric heater is rated 1500 W. How much energy does it use in 10 hours?
15. Illustrate the law of conservation of energy by discussing the energy changes which occur when we draw a pendulum bob to one side and allow it to oscillate. Why does the bob eventually come to rest? What happens to its energy eventually? Is it a violation of the law of conservation of energy?
16. An object of mass, *m* is moving with a constant velocity, *v*. How much work should be done on the object in order to bring the object to rest?
17. Calculate the work required to be done to stop a car of 1500 kg moving at a velocity of 60 km/h?
18. In each of the following a force, *F* is acting on an object of mass, *m*. The direction of displacement is from west to east shown by the longer arrow. Observe the diagrams carefully and state whether the work done by the force is negative, positive or zero.



19. Soni says that the acceleration in an object could be zero even when several forces are acting on it. Do you agree with her? Why?
20. Find the energy in kW h consumed in 10 hours by four devices of power 500 W each.
21. A freely falling object eventually stops on reaching the ground. What happenes to its kinetic energy?

Chapter 12

Sound

Everyday we hear sounds from various sources like humans, birds, bells, machines, vehicles, televisions, radios etc. Sound is a form of energy which produces a sensation of hearing in our ears. There are also other forms of energy like mechanical energy, heat energy, light energy etc. We have talked about mechanical energy in the previous chapters. You have been taught about conservation of energy, which states that we can neither create nor destroy energy. We can just change it from one form to another. When you clap, a sound is produced. Can you produce sound without utilising your energy? Which form of energy did you use to produce sound? In this chapter we are going to learn how sound is produced and how it is transmitted through a medium and received by our ear.

12.1 Production of Sound

Activity 12.1

- Take a tuning fork and set it vibrating by striking its prong on a rubber pad. Bring it near your ear.
- Do you hear any sound?
- Touch one of the prongs of the vibrating tuning fork with your finger and share your experience with your friends.
- Now, suspend a table tennis ball or a small plastic ball by a thread from a support [Take a big needle and a thread, put a knot at one end of the thread, and then with the help of the needle pass the thread through the ball]. Touch the ball gently with the prong of a vibrating tuning fork (Fig. 12.1).
- Observe what happens and discuss with your friends.

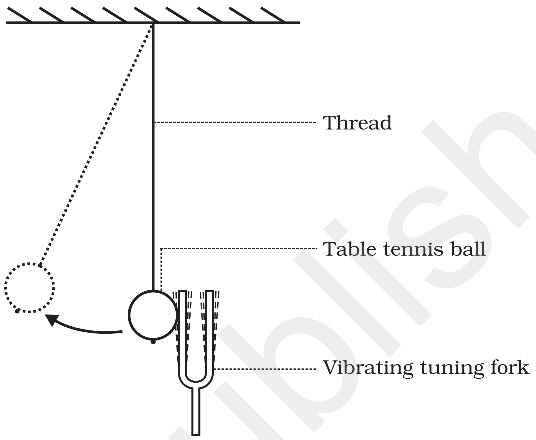


Fig. 12.1: *Vibrating tuning fork just touching the suspended table tennis ball.*

Activity 12.2

- Fill water in a beaker or a glass up to the brim. Gently touch the water surface with one of the prongs of the vibrating tuning fork, as shown in Fig. 12.2.
- Next dip the prongs of the vibrating tuning fork in water, as shown in Fig. 12.3.
- Observe what happens in both the cases.
- Discuss with your friends why this happens.

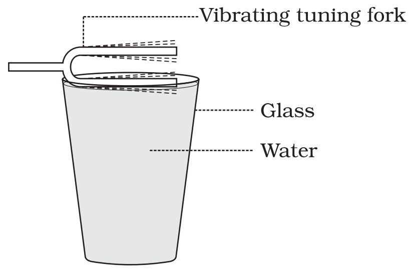


Fig. 12.2: *One of the prongs of the vibrating tuning fork touching the water surface.*

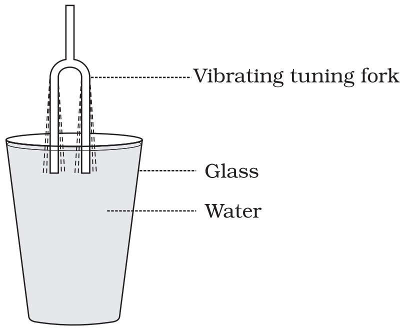


Fig. 12.3: *Both the prongs of the vibrating tuning fork dipped in water.*

From the above activities what do you conclude? Can you produce sound without a vibrating object?

In the above activities we have produced sound by striking the tuning fork. We can also produce sound by plucking, scratching, rubbing, blowing or shaking different objects. As per the above activities what do we do to the objects? We set the objects vibrating and produce sound. Vibration means a kind of rapid to and fro motion of an object. The sound of the human voice is produced due to vibrations in the vocal cords. When a bird flaps its wings, do you hear any sound? Think how the buzzing sound accompanying a bee is produced. A stretched rubber band when plucked vibrates and produces sound. If you have never done this, then do it and observe the vibration of the stretched rubber band.

Activity ______________ *12.3*

- Make a list of different types of musical instruments and discuss with your friends which part of the instrument vibrates to produce sound.

12.2 Propagation of Sound

Sound is produced by vibrating objects. The matter or substance through which sound is transmitted is called a medium. It can be solid, liquid or gas. Sound moves through a medium from the point of generation to the listener. When an object vibrates, it sets the particles of the medium around it vibrating. The particles do not travel all the way from the vibrating object to the ear. A particle of the medium in contact with the vibrating object is first displaced from its equilibrium position. It then exerts a force on the adjacent particle. As a result of which the adjacent particle gets displaced from its position of rest. After displacing the adjacent particle the first particle comes back to its original position. This process continues in the medium till the sound reaches your ear. The disturbance created by a source of sound in

Can sound make a light spot dance?

Take a tin can. Remove both ends to make it a hollow cylinder. Take a balloon and stretch it over the can, then wrap a rubber band around the balloon. Take a small piece of mirror. Use a drop of glue to stick the piece of mirror to the balloon. Allow the light through a slit to fall on the mirror. After reflection the light spot is seen on the wall, as shown in Fig. 12.4. Talk or shout directly into the open end of the can and observe the dancing light spot on the wall. Discuss with your friends what makes the light spot dance.

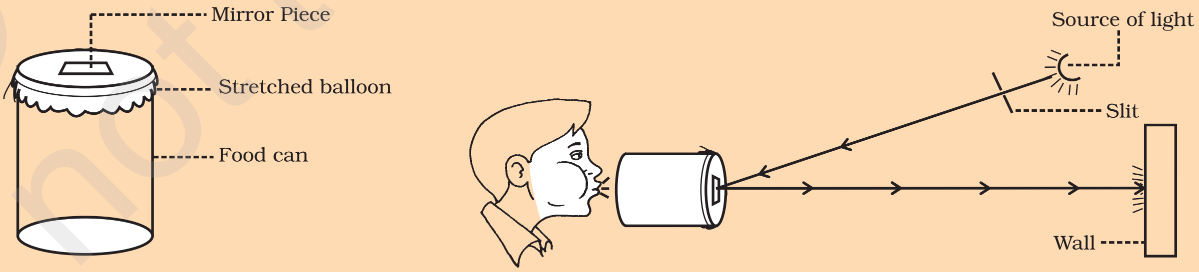


Fig. 12.4: *A beam of light from a light source is made to fall on a mirror. The reflected light is falling on the wall.*

the medium travels through the medium and not the particles of the medium.

A wave is a disturbance that moves through a medium when the particles of the medium set neighbouring particles into motion. They in turn produce similar motion in others. The particles of the medium do not move forward themselves, but the disturbance is carried forward. This is what happens during propagation of sound in a medium, hence sound can be visualised as a wave. Sound waves are characterised by the motion of particles in the medium and are called mechanical waves.

Air is the most common medium through which sound travels. When a vibrating object moves forward, it pushes and compresses the air in front of it creating a region of high pressure. This region is called a compression (C), as shown in Fig. 12.5. This compression starts to move away from the vibrating object. When the vibrating object moves backwards, it creates a region of low pressure called rarefaction (R), as shown in Fig. 12.5. As the object moves back and forth rapidly, a series of compressions and rarefactions is created in the air. These make the sound wave that propagates through the medium. Compression is the region of high pressure and rarefaction is the region of low pressure. Pressure is related to the number of particles of a medium in a given volume. More density of the particles in the medium gives more pressure and vice versa. Thus, propagation of sound can be visualised as propagation of density variations or pressure variations in the medium.

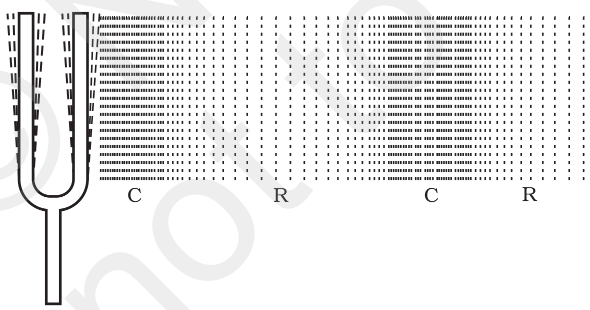


Fig. 12.5: *A vibrating object creating a series of compressions (C) and rarefactions (R) in the medium.*

Question

1. *How does the sound produced by a vibrating object in a medium reach your ear?*

12.2.1 Sound needs a medium to travel

Sound is a mechanical wave and needs a material medium like air, water, steel etc. for its propagation. It cannot travel through vacuum, which can be demonstrated by the following experiment.

Take an electric bell and an airtight glass bell jar. The electric bell is suspended inside the airtight bell jar. The bell jar is connected to a vacuum pump, as shown in Fig. 12.6. If you press the switch you will be able to hear the bell. Now start the vacuum pump. When the air in the jar is pumped out gradually, the sound becomes fainter, although the same current is passing through the bell. After some time when less air is left inside the bell jar you will hear a very feeble sound. What will happen if the air is removed completely? Will you still be able to hear the sound of the bell?

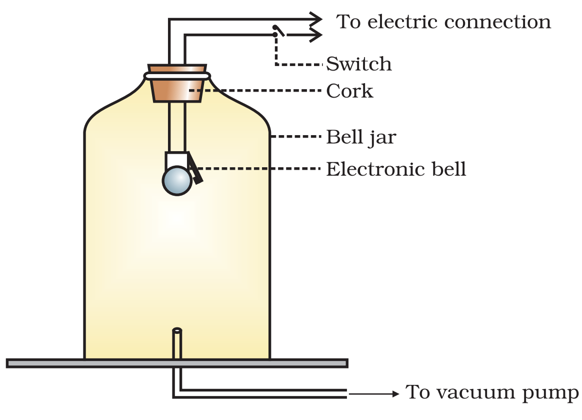


Fig. 12.6: *Bell jar experiment showing sound cannot travel in vacuum.*

Questions

1. *Explain how sound is produced by your school bell.*
2. *Why are sound waves called mechanical waves?*
3. *Suppose you and your friend are on the moon. Will you be able to hear any sound produced by your friend?*

12.2.2 Sound waves are longitudinal waves

Activity 12.4

- Take a slinky. Ask your friend to hold one end. You hold the other end. Now stretch the slinky as shown in Fig. 12.7 (a). Then give it a sharp push towards your friend.
- What do you notice? If you move your hand pushing and pulling the slinky alternatively, what will you observe?
- If you mark a dot on the slinky, you will observe that the dot on the slinky will move back and forth parallel to the direction of the propagation of the disturbance.

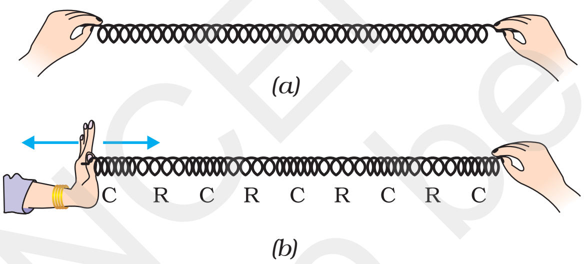


Fig. 12.7: *Longitudinal wave in a slinky.*

The regions where the coils become closer are called compressions (C) and the regions where the coils are further apart are called rarefactions (R). As we already know, sound propagates in the medium as a series of compressions and rarefactions. Now, we can compare the propagation of disturbance in a slinky with the sound propagation in the medium. These waves are called longitudinal waves. In these waves the individual particles of the medium move in a direction parallel to the direction of propagation of the disturbance. The particles do not move from one place to another but they simply oscillate back and forth about their position of rest. This is exactly how a sound wave propagates, hence sound waves are longitudinal waves.

There is also another type of wave, called a transverse wave. In a transverse wave particles do not oscillate along the line of wave propagation but oscillate up and down about their mean position as the wave travels. Thus a transverse wave is the one in which the individual particles of the medium move about their mean positions in a direction perpendicular to the direction of wave propagation. Light is a transverse wave but for light, the oscillations are not of the medium particles or their pressure or density – it is not a mechanical wave. You will come to know more about transverse waves in higher classes.

12.2.3 Characteristics of a sound wave

We can describe a sound wave by its

- frequency
- amplitude and
- speed.

A sound wave in graphic form is shown in Fig. 12.8(c), which represents how density and pressure change when the sound wave moves in the medium. The density as well as the pressure of the medium at a given time varies with distance, above and below the average value of density and pressure. Fig. 12.8(a) and Fig. 12.8(b) represent the density and pressure variations, respectively, as a sound wave propagates in the medium.

Compressions are the regions where particles are crowded together and represented by the upper portion of the curve in Fig. 12.8(c). The peak represents the region of maximum compression. Thus, compressions are regions where density as well as pressure is high. Rarefactions are the regions of low pressure where particles are spread apart and are represented by the

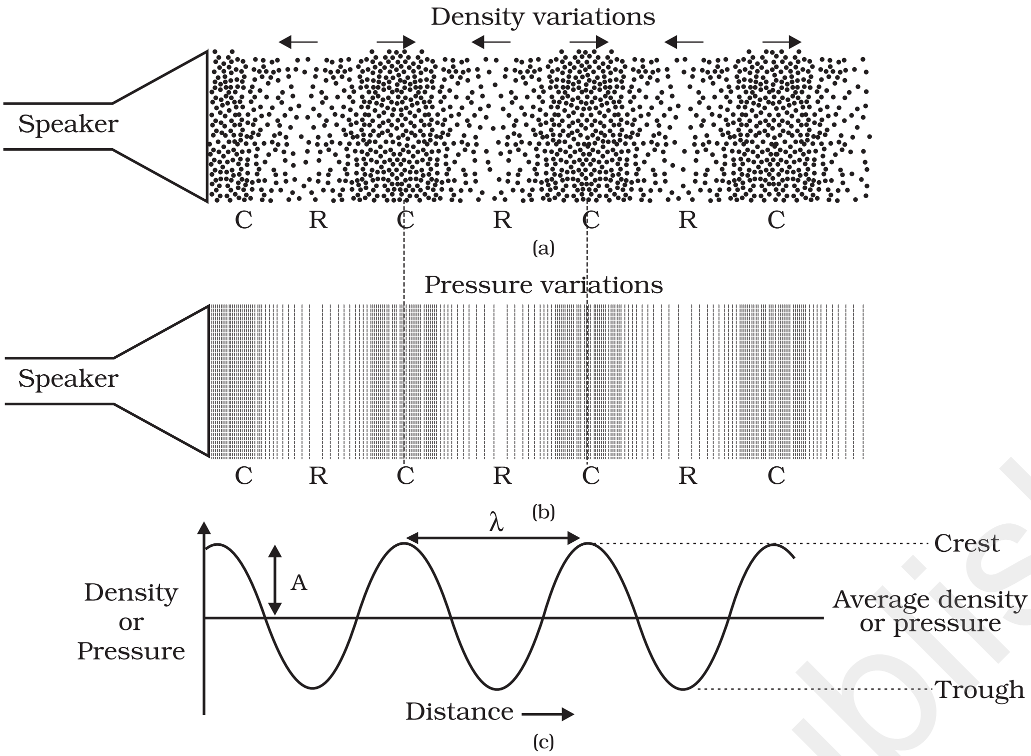


Fig. 12.8: *Sound propagates as density or pressure variations as shown in (a) and (b), (c) represents graphically the density and pressure variations.*

valley, that is, the lower portion of the curve in Fig. 12.8(c). A peak is called the crest and a valley is called the trough of a wave.

The distance between two consecutive compressions (C) or two consecutive rarefactions (R) is called the wavelength, as shown in Fig. 12.8(c), The wavelength is usually represented by λ (Greek letter lambda). Its SI unit is metre (m).

H. R. Hertz

Heinrich Rudolph Hertz was born on 22 February 1857 in Hamburg, Germany and educated at the University of Berlin. He confirmed J.C. Maxwell's electromagnetic theory by his experiments. He laid the foundation for future development of radio, telephone, telegraph and even television. He also discovered the photoelectric effect which was later explained by Albert Einstein. The SI unit of frequency was named as hertz in his honour.

Frequency tells us how frequently an event occurs. Suppose you are beating a drum. How many times you are beating the drum per unit time is called the frequency of your beating the drum. We know that when sound is propagated through a medium, the density of the medium oscillates between a maximum value and a minimum value. The change in density from the maximum value to the minimum value, again to the maximum value, makes one complete oscillation. The number of such oscillations per unit time is the frequency of the sound wave. If we can count the number of the compressions or rarefactions that cross us per unit time, we will get the frequency of the sound wave. It is usually represented by ν (Greek letter, nu). Its SI unit is hertz (symbol, Hz).

The time taken by two consecutive compressions or rarefactions to cross a fixed point is called the time period of the wave. In other words, we can say that the time taken for one complete oscillation in the density of the medium is called the time period of the sound wave. It is represented by the symbol *T*. Its SI unit is second (s). Frequency and time period are related as follows:

$$\frac{1}{T}.$$

A violin and a flute may both be played at the same time in an orchestra. Both sounds travel through the same medium, that is, air and arrive at our ear at the same time. Both sounds travel at the same speed irrespective of the source. But the sounds we receive are different. This is due to the different characteristics associated with the sound. Pitch is one of the characteristics.

How the brain interprets the frequency of an emitted sound is called its pitch. The faster the vibration of the source, the higher is the frequency and the higher is the pitch, as shown in Fig. 12.9. Thus, a high pitch sound corresponds to more number of compressions and rarefactions passing a fixed point per unit time.

Objects of different sizes and conditions vibrate at different frequencies to produce sounds of different pitch.

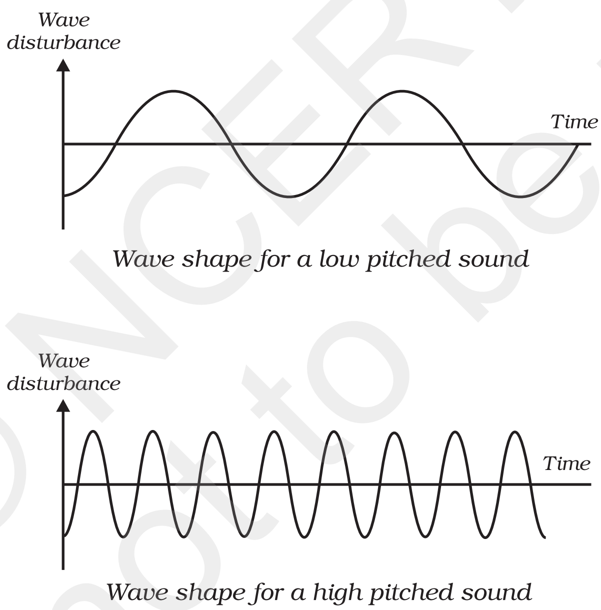


Fig. 12.9: *Low pitch sound has low frequency and high pitch of sound has high frequency.*

The magnitude of the maximum disturbance in the medium on either side of the mean value is called the amplitude of the wave. It is usually represented by the letter A, as shown in Fig. 12.8(c). For sound its unit will be that of density or pressure.

The loudness or softness of a sound is determined basically by its amplitude. The amplitude of the sound wave depends upon the force with which an object is made to vibrate. If we strike a table lightly, we hear a soft sound because we produce a sound wave of less energy (amplitude). If we hit the table hard we hear a loud sound. Can you tell why? Loud sound can travel a larger distance as it is associated with higher energy. A sound wave spreads out from its source. As it moves away from the source its amplitude as well as its loudness decreases. Fig. 12.10 shows the wave shapes of a loud and a soft sound of the same frequency.

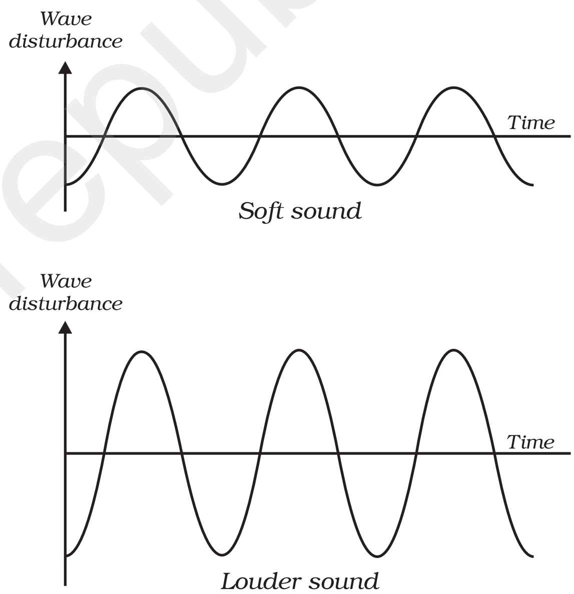


Fig. 12.10: *Soft sound has small amplitude and louder sound has large amplitude.*

The quality or timber of sound is that characteristic which enables us to distinguish one sound from another having the same pitch and loudness. The sound which is more pleasant is said to be of a rich quality. A sound of single frequency is called a tone. The sound which is produced due to a mixture of several frequencies is called a note and is pleasant to listen to. Noise is unpleasant to the ear! Music is pleasant to hear and is of rich quality.

Questions

1. *Which wave property determines (a) loudness, (b) pitch?*
2. *Guess which sound has a higher pitch: guitar or car horn?*

The speed of sound is defined as the distance which a point on a wave, such as a compression or a rarefaction, travels per unit time.

We know,

speed, v = distance / time

$$= \frac{}{T}$$

Here λ is the wavelength of the sound wave. It is the distance travelled by the sound wave in one time period (T) of the wave. Thus,

$$v = \lambda \nu \quad \because \frac{1}{T}$$

or $\quad v = \lambda \nu$

That is, speed = wavelength × frequency.

The speed of sound remains almost the same for all frequencies in a given medium under the same physical conditions.

Example 12.1 A sound wave has a frequency of 2 kHz and wave length 35 cm. How long will it take to travel 1.5 km?

Solution:

Given,

Frequency, ν = 2 kHz = 2000 Hz

Wavelength, λ = 35 cm = 0.35 m

We know that speed, v of the wave

= wavelength × frequency

$v = \lambda \nu$

= 0.35 m × 2000 Hz = 700 m/s

The time taken by the wave to travel a distance, d of 1.5 km is

Thus sound will take 2.1 s to travel a distance of 1.5 km.

Questions

1. *What are wavelength, frequency, time period and amplitude of a sound wave?*
2. *How are the wavelength and frequency of a sound wave related to its speed?*
3. *Calculate the wavelength of a sound wave whose frequency is 220 Hz and speed is 440 m/s in a given medium.*
4. *A person is listening to a tone of 500 Hz sitting at a distance of 450 m from the source of the sound. What is the time interval between successive compressions from the source?*

The amount of sound energy passing each second through unit area is called the intensity of sound. We sometimes use the terms "loudness" and "intensity" interchangeably, but they are not the same. Loudness is a measure of the response of the ear to the sound. Even when two sounds are of equal intensity, we may hear one as louder than the other simply because our ear detects it better.

Question

1. *Distinguish between loudness and intensity of sound.*

12.2.4 SPEED OF SOUND IN DIFFERENT MEDIA

Sound propagates through a medium at a finite speed. The sound of a thunder is heard a little later than the flash of light is seen.

So, we can make out that sound travels with a speed which is much less than the speed of light. The speed of sound depends on the properties of the medium through which it travels. You will learn about this dependence in higher classes. The speed of sound in a medium depends on temperature of the medium. The speed of sound decreases when we go from solid to gaseous state. In any medium as we increase the temperature the speed of sound increases. For example, the speed of sound in air is 331 m s^{-1} at 0 ŢC and 344 m s^{-1} at 22 ŢC. The speeds of sound at a particular temperature in various media are listed in Table 12.1. You need not memorise the values.

Table 12.1: Speed of sound in different media at 25 ŢC

State	Substance	Speed in m/s
Solids	Aluminium	6420
	Nickel	6040
	Steel	5960
	Iron	5950
	Brass	4700
	Glass (Flint)	3980
Liquids	Water (Sea)	1531
	Water (distilled)	1498
	Ethanol	1207
	Methanol	1103
Gases	Hydrogen	1284
	Helium	965
	Air	346
	Oxygen	316
	Sulphur dioxide	213

Question

1. *In which of the three media, air, water or iron, does sound travel the fastest at a particular temperature?*

Sonic boom: When the speed of any object exceeds the speed of sound it is said to be travelling at supersonic speed. Bullets, jet aircrafts etc. often travel at supersonic speeds. When a sound, producing source moves with a speed higher than that of sound, it produces shock waves in air. These shock waves carry a large amount of energy. The air pressure variation associated with this type of shock waves produces a very sharp and loud sound called the "sonic boom". The shock waves produced by a supersonic aircraft have enough energy to shatter glass and even damage buildings.

12.3 Reflection of Sound

Sound bounces off a solid or a liquid like a rubber ball bounces off a wall. Like light, sound gets reflected at the surface of a solid or liquid and follows the same laws of reflection as you have studied in earlier classes. The directions in which the sound is incident and is reflected make equal angles with the normal to the reflecting surface at the point of incidence, and the three are in the same plane. An obstacle of large size which may be polished or rough is needed for the reflection of sound waves.

Activity 12.5

- Take two identical pipes, as shown in Fig. 12.11. You can make the pipes using chart paper. The length of the pipes should be sufficiently long as shown.
- Arrange them on a table near a wall.
- Keep a clock near the open end of one of the pipes and try to hear the sound of the clock through the other pipe.
- Adjust the position of the pipes so that you can best hear the sound of the clock.
- Now, measure the angles of incidence and reflection and see the relationship between the angles.
- Lift the pipe on the right vertically to a small height and observe what happens.

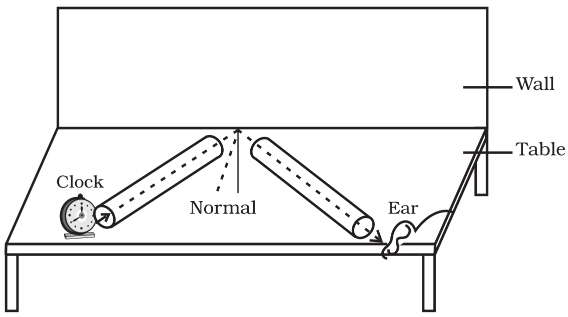


Fig. 12.11: *Reflection of sound*

12.3.1 Echo

If we shout or clap near a suitable reflecting object such as a tall building or a mountain, we will hear the same sound again a little later. This sound which we hear is called an echo. The sensation of sound persists in our brain for about 0.1 s. To hear a distinct echo the time interval between the original sound and the reflected one must be at least 0.1s. If we take the speed of sound to be 344 m/s at a given temperature, say at 22 ºC in air, the sound must go to the obstacle and reach back the ear of the listener on reflection after 0.1s. Hence, the total distance covered by the sound from the point of generation to the reflecting surface and back should be at least (344 m/s) $\times$ 0.1 s = 34.4 m. Thus, for hearing distinct echoes, the minimum distance of the obstacle from the source of sound must be half of this distance, that is, 17.2 m. This distance will change with the temperature of air. Echoes may be heard more than once due to successive or multiple reflections. The rolling of thunder is due to the successive reflections of the sound from a number of reflecting surfaces, such as the clouds and the land.

12.3.2 Reverberation

A sound created in a big hall will persist by repeated reflection from the walls until it is reduced to a value where it is no longer audible. The repeated reflection that results in this persistence of sound is called reverberation. In an auditorium or big hall excessive reverberation is highly undesirable. To reduce reverberation, the roof and walls of the auditorium are generally covered with sound-absorbent materials like compressed fibreboard, rough plaster or draperies. The seat materials are also selected on the basis of their sound absorbing properties.

Example 12.2 A person clapped his hands near a cliff and heard the echo after 5 s. What is the distance of the cliff from the person if the speed of the sound, v is taken as 346 m s^{-1}?

Solution:

Given,
Speed of sound, v = 346 m s^{-1}
Time taken for hearing the echo,
t = 5 s
Distance travelled by the sound
= $v \times t$ = 346 m s^{-1} $\times$ 5 s = 1730 m
In 5 s sound has to travel twice the distance between the cliff and the person. Hence, the distance between the cliff and the person
= 1730 m/2 = 865 m.

Question

1. *An echo returned in 3 s. What is the distance of the reflecting surface from the source, given that the speed of sound is 342 m s^{-1}?*

12.3.3 Uses of multiple reflection of sound

1. Megaphones or loudhailers, horns, musical instruments such as trumpets and *shehanais*, are all designed to send sound in a particular direction without spreading it in all directions, as shown in Fig 12.12.

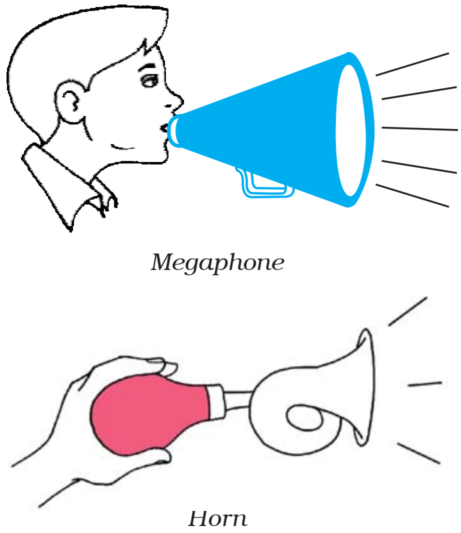


Fig 12.12: *A megaphone and a horn.*

In these instruments, a tube followed by a conical opening reflects sound successively to guide most of the sound waves from the source in the forward direction towards the audience.

2. Stethoscope is a medical instrument used for listening to sounds produced within the body, chiefly in the heart or lungs. In stethoscopes the sound of the patient's heartbeat reaches the doctor's ears by multiple reflection of sound, as shown in Fig.12.13.

Fig.12.13: *Stethoscope*

3. Generally the ceilings of concert halls, conference halls and cinema halls are curved so that sound after reflection reaches all corners of the hall, as shown in Fig 12.14. Sometimes a curved soundboard may be placed behind the stage so that the sound, after reflecting from the sound board, spreads evenly across the width of the hall (Fig 12.15).

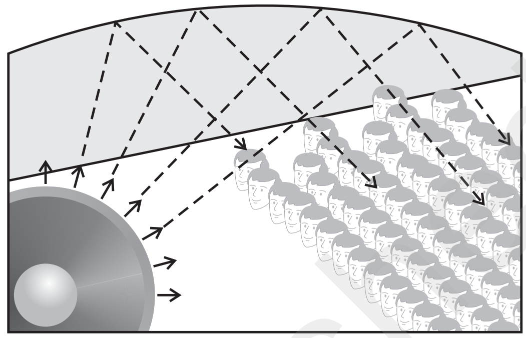


Fig. 12.14: *Curved ceiling of a conference hall.*

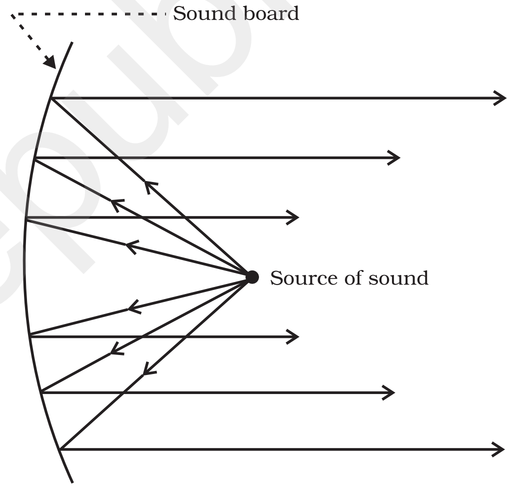


Fig. 12.15: *Sound board used in a big hall.*

Question

1. *Why are the ceilings of concert halls curved?*

12.4 Range of Hearing

The audible range of sound for human beings extends from about 20 Hz to 20000 Hz (one Hz = one cycle/s). Children under the age of five and some animals, such as dogs can hear up to 25 kHz (1 kHz = 1000 Hz). As people grow older their ears become less sensitive to higher frequencies. Sounds of frequencies below 20 Hz are called infrasonic sound or infrasound. If we could hear infrasound we would hear the vibrations of a pendulum just as we hear the vibrations of the wings of a bee. Rhinoceroses communicate using infrasound of frequency as low as 5 Hz. Whales and elephants produce sound in the infrasound range. It is observed that some animals get disturbed before earthquakes. Earthquakes produce low-frequency infrasound before the main shock waves begin which possibly alert the animals. Frequencies higher than 20 kHz are called ultrasonic sound or ultrasound. Ultrasound is produced by dolphins, bats and porpoises. Moths of certain families have very sensitive hearing equipment. These moths can hear the high frequency squeaks of the bat and know when a bat is flying nearby, and are able to escape capture. Rats also play games by producing ultrasound.

Hearing Aid: People with hearing loss may need a hearing aid. A hearing aid is an electronic, battery operated device. The hearing aid receives sound through a microphone. The microphone converts the sound waves to electrical signals. These electrical signals are amplified by an amplifier. The amplified electrical signals are given to a speaker of the hearing aid. The speaker converts the amplified electrical signal to sound and sends to the ear for clear hearing.

Questions

1. *What is the audible range of the average human ear?*
2. *What is the range of frequencies associated with*
   (a) Infrasound?
   (b) Ultrasound?

12.5 Applications of Ultrasound

Ultrasounds are high frequency waves. Ultrasounds are able to travel along well-defined paths even in the presence of obstacles. Ultrasounds are used extensively in industries and for medical purposes.

- Ultrasound is generally used to clean parts located in hard-to-reach places, for example, spiral tube, odd shaped parts, electronic components etc. Objects to be cleaned are placed in a cleaning solution and ultrasonic waves are sent into the solution. Due to the high frequency, the particles of dust, grease and dirt get detached and drop out. The objects thus get thoroughly cleaned.
- Ultrasounds can be used to detect cracks and flaws in metal blocks. Metallic components are generally used in construction of big structures like buildings, bridges, machines and also scientific equipment. The cracks or holes inside the metal blocks, which are invisible from outside reduces the strength of the structure. Ultrasonic waves are allowed to pass through the metal block and detectors are used to detect the transmitted waves. If there is even a small defect, the ultrasound gets reflected back indicating the presence of the flaw or defect, as shown in Fig. 12.16.

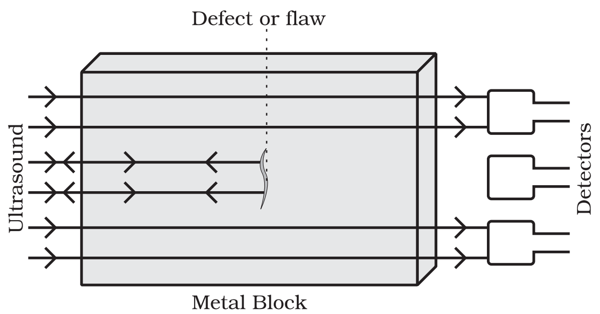


Fig 12.16: *Ultrasound is reflected back from the defective locations inside a metal block.*

Ordinary sound of longer wavelengths cannot be used for such purpose as it will bend around the corners of the defective location and enter the detector.

- Ultrasonic waves are made to reflect from various parts of the heart and form the image of the heart. This technique is called 'echocardiography'.
- Ultrasound scanner is an instrument which uses ultrasonic waves for getting images of internal organs of the human body. A doctor may image the patient's organs such as the liver, gall bladder, uterus, kidney, etc. It helps the doctor to detect abnormalities, such as stones in the gall bladder and kidney or tumours in different organs. In this technique the ultrasonic waves travel through the tissues of the body and get reflected from a region where there is a change of tissue density. These waves are then converted into electrical signals that are used to generate images of the organ. These images are then displayed on a monitor or printed on a film. This technique is called 'ultrasonography'. Ultrasonography is also used for examination of the foetus during pregnancy to detect congenial defects and growth abnormalities.
- Ultrasound may be employed to break small 'stones' formed in the kidneys into fine grains. These grains later get flushed out with urine.

12.5.1 SONAR

The acronym SONAR stands for SOund Navigation And Ranging. Sonar is a device that uses ultrasonic waves to measure the distance, direction and speed of underwater objects. How does the sonar work? Sonar consists of a transmitter and a detector and is installed in a boat or a ship, as shown in Fig. 12.17.

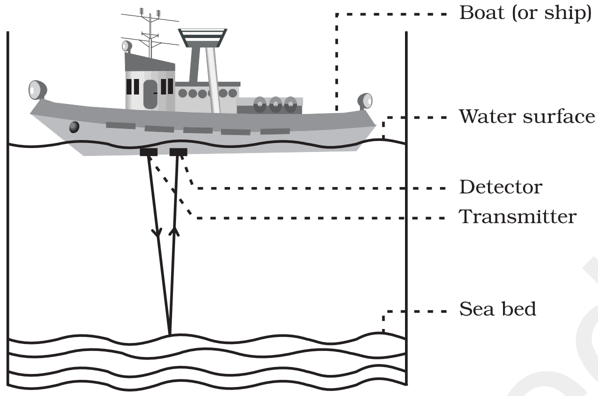


Fig.12.17: *Ultrasound sent by the transmitter and received by the detector.*

The transmitter produces and transmits ultrasonic waves. These waves travel through water and after striking the object on the seabed, get reflected back and are sensed by the detector. The detector converts the ultrasonic waves into electrical signals which are appropriately interpreted. The distance of the object that reflected the sound wave can be calculated by knowing the speed of sound in water and the time interval between transmission and reception of the ultrasound. Let the time interval between transmission and reception of ultrasound signal be t and the speed of sound through seawater be v. The total distance, $2d$ travelled by the ultrasound is then, $2d = v \times t$.

The above method is called echo-ranging. The sonar technique is used to determine the depth of the sea and to locate underwater hills, valleys, submarine, icebergs, sunken ship etc.

Example 12.3 A ship sends out ultrasound that returns from the seabed and is detected after 3.42 s. If the speed of ultrasound through seawater is 1531 m/s, what is the distance of the seabed from the ship?

Solution:

Given,
Time between transmission and detection, t = 3.42 s.

Speed of ultrasound in sea water,

v = 1531 m/s

Distance travelled by the ultrasound

= 2 × depth of the sea = $2d$

where d is the depth of the sea.

$2d$ = speed of sound × time

= 1531 m/s × 3.42 s = 5236 m

d = 5236 m/2 = 2618 m.

Thus, the distance of the seabed from the ship is 2618 m or 2.62 km.

Question

1. *A submarine emits a sonar pulse, which returns from an underwater cliff in 1.02 s. If the speed of sound in salt water is 1531 m/s, how far away is the cliff?*

As mentioned earlier, bats search out prey and fly in dark night by emitting and detecting reflections of ultrasonic waves. The high-pitched ultrasonic squeaks of the bat are reflected from the obstacles or prey and returned to bat's ear, as shown in Fig. 12.18. The nature of reflections tells the bat where the obstacle or prey is and what it is like. Porpoises also use ultrasound for navigation and location of food in the dark.

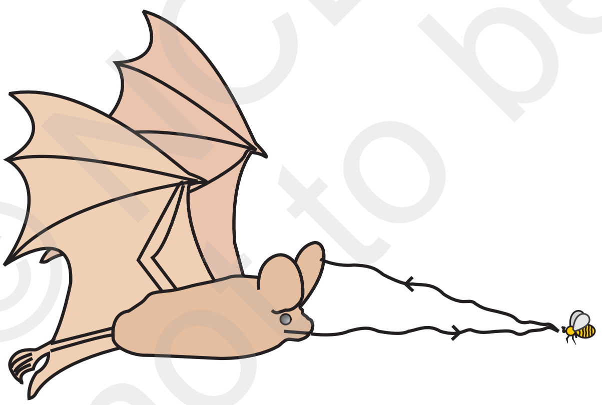


Fig. 12.18: *Ultrasound is emitted by a bat and it is reflected back by the prey or an obstacle.*

12.6 Structure of Human Ear

How do we hear? We are able to hear with the help of an extremely sensitive device called the ear. It allows us to convert pressure variations in air with audible frequencies into electric signals that travel to the brain via the auditory nerve. The auditory aspect of human ear is discussed below.

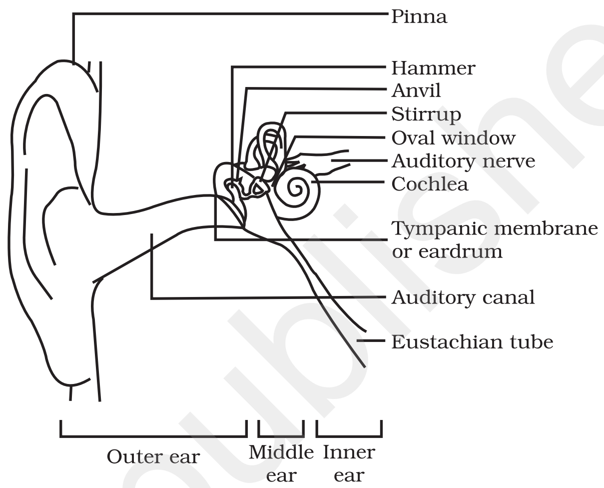


Fig. 12.19: *Auditory parts of human ear.*

The outer ear is called 'pinna'. It collects the sound from the surroundings. The collected sound passes through the auditory canal. At the end of the auditory canal there is a thin membrane called the ear drum or tympanic membrane. When a compression of the medium reaches the eardrum the pressure on the outside of the membrane increases and forces the eardrum inward. Similarly, the eardrum moves outward when a rarefaction reaches it. In this way the eardrum vibrates. The vibrations are amplified several times by three bones (the hammer, anvil and stirrup) in the middle ear. The middle ear transmits the amplified pressure variations received from the sound wave to the inner ear. In the inner ear, the pressure variations are turned into electrical signals by the cochlea. These electrical signals are sent to the brain via the auditory nerve, and the brain interprets them as sound.

What you have learnt

- Sound is produced due to vibration of different objects.
- Sound travels as a longitudinal wave through a material medium.
- Sound travels as successive compressions and rarefactions in the medium.
- In sound propagation, it is the energy of the sound that travels and not the particles of the medium.
- Sound cannot travel in vacuum.
- The change in density from one maximum value to the minimum value and again to the maximum value makes one complete oscillation.
- The distance between two consecutive compressions or two consecutive rarefactions is called the wavelength, λ.
- The time taken by the wave for one complete oscillation of the density or pressure of the medium is called the time period, T.
- The number of complete oscillations per unit time is called the frequency (ν), $\frac{1}{T}$.
- The speed v, frequency ν, and wavelength λ, of sound are related by the equation, $v = \lambda\nu$.
- The speed of sound depends primarily on the nature and the temperature of the transmitting medium.
- The law of reflection of sound states that the directions in which the sound is incident and reflected make equal angles with the normal to the reflecting surface at the point of incidence and the three lie in the same plane.
- For hearing a distinct sound, the time interval between the original sound and the reflected one must be at least 0.1 s.
- The persistence of sound in an auditorium is the result of repeated reflections of sound and is called reverberation.
- Sound properties such as pitch, loudness and quality are determined by the corresponding wave properties.
- Loudness is a physiological response of the ear to the intensity of sound.
- The amount of sound energy passing each second through unit area is called the intensity of sound.
- The audible range of hearing for average human beings is in the frequency range of 20 Hz – 20 kHz.

- Sound waves with frequencies below the audible range are termed "infrasonic" and those above the audible range are termed "ultrasonic".
- Ultrasound has many medical and industrial applications.
- The SONAR technique is used to determine the depth of the sea and to locate under water hills, valleys, submarines, icebergs, sunken ships etc.

Exercises

1. What is sound and how is it produced?
2. Describe with the help of a diagram, how compressions and rarefactions are produced in air near a source of sound.
3. Cite an experiment to show that sound needs a material medium for its propagation.
4. Why is sound wave called a longitudinal wave?
5. Which characteristic of the sound helps you to identify your friend by his voice while sitting with others in a dark room?
6. Flash and thunder are produced simultaneously. But thunder is heard a few seconds after the flash is seen, why?
7. A person has a hearing range from 20 Hz to 20 kHz. What are the typical wavelengths of sound waves in air corresponding to these two frequencies? Take the speed of sound in air as 344 m s^{-1}.
8. Two children are at opposite ends of an aluminium rod. One strikes the end of the rod with a stone. Find the ratio of times taken by the sound wave in air and in aluminium to reach the second child.
9. The frequency of a source of sound is 100 Hz. How many times does it vibrate in a minute?
10. Does sound follow the same laws of reflection as light does? Explain.
11. When a sound is reflected from a distant object, an echo is produced. Let the distance between the reflecting surface and the source of sound production remains the same. Do you hear echo sound on a hotter day?
12. Give two practical applications of reflection of sound waves.
13. A stone is dropped from the top of a tower 500 m high into a pond of water at the base of the tower. When is the splash heard at the top? Given, g = 10 m s^{-2} and speed of sound = 340 m s^{-1}.
14. A sound wave travels at a speed of 339 m s^{-1}. If its wavelength is 1.5 cm, what is the frequency of the wave?

Will it be audible?

15. What is reverberation? How can it be reduced?
16. What is loudness of sound? What factors does it depend on?
17. Explain how bats use ultrasound to catch a prey.
18. How is ultrasound used for cleaning?
19. Explain the working and application of a sonar.
20. A sonar device on a submarine sends out a signal and receives an echo 5 s later. Calculate the speed of sound in water if the distance of the object from the submarine is 3625 m.
21. Explain how defects in a metal block can be detected using ultrasound.
22. Explain how the human ear works.

Chapter 13

WHY DO WE FALL ILL

Activity ______________ *13.1*

- We have all heard of the earthquakes in Latur, Bhuj, Kashmir etc. or the cyclones that attack the coastal regions. Think of as many different ways as possible in which people's health would be affected by such a disaster if it took place in our neighbourhood.
- How many of these ways we can think of are events that would occur when the disaster is actually happening?
- How many of these health-related events would happen long after the actual disaster, but would still be because of the disaster?
- Why would one effect on health fall into the first group, and why would another fall into the second group?

When we do this exercise, we realise that health and disease in human communities are very complex issues, with many interconnected causes. We also realise that the ideas of what 'health' and 'disease' mean are themselves very complicated. When we ask what causes diseases and how we prevent them, we have to begin by asking what these notions mean.

We have seen that cells are the basic units of living beings. Cells are made of a variety of chemical substances – proteins, carbohydrates, fats or lipids, and so on. Although the pictures look quite static, in reality the living cell is a dynamic place. Something or the other is always happening. Cells move from place to place. Even in cells that do not move, there is repair going on. New cells are being made. In our organs or tissues, there are various specialised activities going on – the heart is beating, the lungs are breathing, the kidney is filtering urine, the brain is thinking.

All these activities are interconnected. For example, if the kidneys are not filtering urine, poisonous substances will accumulate. Under such conditions, the brain will not be able to think properly. For all these interconnected activities, energy and raw material are needed from outside the body. In other words, food is a necessity for cell and tissue functions. Anything that prevents proper functioning of cells and tissues will lead to a lack of proper activity of the body.

It is in this context that we will now look at the notions of health and disease.

13.1 Health and its Failure

13.1.1 THE SIGNIFICANCE OF 'HEALTH'

We have heard the word 'health' used quite frequently all around us. We use it ourselves as well, when we say things like 'my grandmother's health is not good'. Our teachers use it when they scold us saying 'this is not a healthy attitude'. What does the word 'health' mean?

If we think about it, we realise that it always implies the idea of 'being well'. We can think of this well-being as effective functioning. For our grandmothers, being able to go out to the market or to visit neighbours is 'being well', and not being able to do such things is 'poor health'. Being interested in following the teaching in the classroom so that we can understand the world is called a 'healthy attitude'; while not being interested is called the opposite. 'Health' is therefore a state of being well enough to function well physically, mentally and socially.

13.1.2 Personal and Community Issues Both Matter for Health

If health means a state of physical, mental and social well-being, it cannot be something that each one of us can achieve entirely on our own. The health of all organisms will depend on their surroundings or their environment. The environment includes the physical environment. So, for example, health is at risk in a cyclone in many ways.

But even more importantly, human beings live in societies. Our social environment, therefore, is an important factor in our individual health. We live in villages, towns or cities. In such places, even our physical environment is decided by our social environment.

Consider what would happen if no agency is ensuring that garbage is collected and disposed. What would happen if no one takes responsibility for clearing the drains and ensuring that water does not collect in the streets or open spaces?

So, if there is a great deal of garbage thrown in our streets, or if there is open drain-water lying stagnant around where we live, the possibility of poor health increases. Therefore, public cleanliness is important for individual health.

Activity 13.2

- Find out what provisions are made by your local authority (panchayat/ municipal corporation) for the supply of clean drinking water.
- Are all the people in your locality able to access this?

Activity 13.3

- Find out how your local authority manages the solid waste generated in your neighbourhood.
- Are these measures adequate?
- If not, what improvements would you suggest?
- What could your family do to reduce the amount of solid waste generated during a day/week?

We need food for health, and this food will have to be earned by doing work. For this, the opportunity to do work has to be available. Good economic conditions and jobs are therefore needed for individual health.

We need to be happy in order to be truly healthy, and if we mistreat each other and are afraid of each other, we cannot be happy or healthy. Social equality and harmony are therefore necessary for individual health. We can think of many other such examples of connections between community issues and individual health.

13.1.3 Distinctions Between 'Healthy' and 'Disease-Free'

If this is what we mean by 'health', what do we mean by 'disease'? The word is actually self-explanatory – we can think of it as 'disease' – disturbed ease. Disease, in other words, literally means being uncomfortable. However, the word is used in a more limited meaning. We talk of disease when we can find a specific and particular cause for discomfort. This does not mean that we have to know the absolute final cause; we can say that someone is suffering from diarrhoea without knowing exactly what has caused the loose motions.

We can now easily see that it is possible to be in poor health without actually suffering from a particular disease. Simply not being diseased is not the same as being healthy. 'Good health' for a dancer may mean being able to stretch his body into difficult but graceful positions. On the other hand, good health for a musician may mean having enough breathing capacity in his/her lungs to control the notes from his/her flute. To have the opportunity to realise the unique potential in all of us is also necessary for real health.

So, we can be in poor health without there being a simple cause in the form of an identifiable disease. This is the reason why, when we think about health, we think about societies and communities. On the other hand, when we think about disease, we think about individual sufferers.

Questions

1. State any two conditions essential for good health.
2. State any two conditions essential for being free of disease.
3. Are the answers to the above questions necessarily the same or different? Why?

13.2 Disease and Its Causes

13.2.1 What does disease look like?

Let us now think a little more about diseases. In the first place, how do we know that there is a disease? In other words, how do we know that there is something wrong with the body? There are many tissues in the body, as we have seen in Chapter 6. These tissues make up physiological systems or organ systems that carry out body functions. Each of the organ systems has specific organs as its parts, and it has particular functions. So, the digestive system has the stomach and intestines, and it helps to digest food taken in from outside the body. The musculoskeletal system, which is made up of bones and muscles, holds the body parts together and helps the body move.

When there is a disease, either the functioning or the appearance of one or more systems of the body will change for the worse. These changes give rise to symptoms and signs of disease. Symptoms of disease are the things we feel as being 'wrong'. So we have a headache, we have cough, we have loose motions, we have a wound with pus; these are all symptoms. These indicate that there may be a disease, but they don't indicate what the disease is. For example, a headache may mean just examination stress or, very rarely, it may mean meningitis, or any one of a dozen different diseases.

Signs of disease are what physicians will look for on the basis of the symptoms. Signs will give a little more definite indication of the presence of a particular disease. Physicians will also get laboratory tests done to pinpoint the disease further.

13.2.2 Acute and chronic diseases

The manifestations of disease will be different depending on a number of factors. One of the most obvious factors that determine how we perceive the disease is its duration. Some diseases last for only very short periods of time, and these are called acute diseases. We all know from experience that the common cold lasts only a few days. Other ailments can last for a long time, even as much as a lifetime, and are called chronic diseases. An example is the infection causing elephantiasis, which is very common in some parts of India.

Activity 13.4

- Survey your neighbourhood to find out:
  (1) how many people suffered from acute diseases during the last three months,
  (2) how many people developed chronic diseases during this same period,
  (3) and finally, the total number of people suffering from chronic diseases in your neighbourhood.
- Are the answers to questions (1) and (2) different?
- Are the answers to questions (2) and (3) different?
- What do you think could be the reason for these differences? What do you think would be the effect of these differences on the general health of the population?

13.2.3 Chronic diseases and poor health

As we can imagine, acute and chronic diseases have different effects on our health. Any disease that causes poor functioning of some part of the body will affect our general health as well. This is because all functions of the body are necessary for general health. But an acute disease, which is over very soon, will not have time to cause major effects on general health, while a chronic disease will do so.

As an example, think about a cough and cold, which all of us have from time to time. Most of us get better and become well within a week or so. And there are no bad effects on our health. We do not lose weight, we do not become short of breath, we do not feel tired all the time because of a few days of cough and cold. But if we get infected with a chronic disease such as tuberculosis of the lungs, then being ill over the years does make us lose weight and feel tired all the time.

We may not go to school for a few days if we have an acute disease. But a chronic disease will make it difficult for us to follow what is being taught in school and reduce our ability to learn. In other words, we are likely to have prolonged general poor health if we have a chronic disease. Chronic diseases therefore, have very drastic long-term effects on people's health as compared to acute diseases.

13.2.4 Causes of diseases

What causes disease? When we think about causes of diseases, we must remember that there are many levels of such causes. Let us look at an example. If there is a baby suffering from loose motions, we can say that the cause of the loose motions is an infection with a virus. So the immediate cause of the disease is a virus.

But the next question is – where did the virus come from? Suppose we find that the virus came through unclean drinking water. But many babies must have had this unclean drinking water. So, why is it that one baby developed loose motions when the other babies did not?

One reason might be that this baby is not healthy. As a result, it might be more likely to have disease when exposed to risk, whereas healthier babies would not. Why is the baby not healthy? Perhaps because it is not well nourished and does not get enough food. So, lack of good nourishment becomes a second-level cause of the disease the baby is suffering from. Further, why is the baby not well nourished? Perhaps because it is from a household which is poor.

It is also possible that the baby has some genetic difference that makes it more likely to suffer from loose motions when exposed to such a virus. Without the virus, the genetic difference or the poor nourishment alone would not lead to loose motions. But they do become contributory causes of the disease.

Why was there no clean drinking water for the baby? Perhaps because the public services are poor where the baby's family lives. So, poverty or lack of public services become third-level causes of the baby's disease.

It will now be obvious that all diseases will have immediate causes and contributory causes. Also, most diseases will have many causes, rather than one single cause.

13.2.5 Infectious and non-infectious causes

As we have seen, it is important to keep public health and community health factors in mind when we think about causes of diseases. We can take that approach a little further. It is useful to think of the immediate causes of disease as belonging to two distinct types. One group of causes is the infectious agents, mostly microbes or micro-organisms. Diseases where microbes are the immediate causes are called infectious diseases. This is because the microbes can spread in the community, and the diseases they cause will spread with them.

Things to ponder

1. Do all diseases spread to people coming in contact with a sick person?
2. What are the diseases that are not spreading?
3. How would a person develop those diseases that don't spread by contact with a sick person?

On the other hand, there are also diseases that are not caused by infectious agents. Their causes vary, but they are not external causes like microbes that can spread in the community. Instead, these are mostly internal, non-infectious causes.

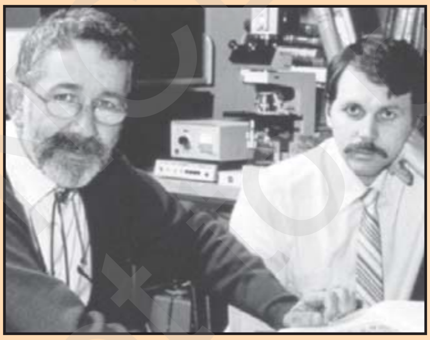
For example, some cancers are caused by genetic abnormalities. High blood pressure can be caused by excessive weight and lack of exercise. You can think of many other diseases where the immediate causes will not be infectious.

Peptic ulcers and the Nobel prize

For many years, everybody used to think that peptic ulcers, which cause acidity–related pain and bleeding in the stomach and duodenum, were because of lifestyle reasons. Everybody thought that a stressful life led to a lot of acid secretion in the stomach, and eventually caused peptic ulcers.

Then two Australians made a discovery that a bacterium, *Helicobacter pylori*, was responsible for peptic ulcers. Robin Warren (born 1937), a pathologist from Perth, Australia, saw these small curved bacteria in the lower part of the stomach in many patients. He noticed that signs of inflammation were always present around these bacteria. Barry Marshall (born 1951), a young clinical fellow, became interested in Warren's findings and succeeded in cultivating the bacteria from these sources.

In treatment studies, Marshall and Warren showed that patients could be cured of peptic ulcer only when the bacteria were killed off from the stomach. Thanks to this pioneering discovery by Marshall and Warren, peptic ulcer disease is no longer a chronic, frequently disabling condition, but a disease that can be cured by a short period of treatment with antibiotics.



For this achievement, Marshall and Warren (seen in the picture) received the Nobel prize for physiology and medicine in 2005.

The ways in which diseases spread, and the ways in which they can be treated and prevented at the community level would be different for different diseases. This would depend a lot on whether the immediate causes are infectious or non-infectious.

Questions

1. *List any three reasons why you would think that you are sick and ought to see a doctor. If only one of these symptoms were present, would you still go to the doctor? Why or why not?*
2. *In which of the following case do you think the long-term effects on your health are likely to be most unpleasant?*
   - *if you get jaundice,*
   - *if you get lice,*
   - *if you get acne.*

   Why?

13.3 Infectious Diseases

13.3.1 Infectious Agents

We have seen that the entire diversity seen in the living world can be classified into a few groups. This classification is based on common characteristics between different organisms. Organisms that can cause disease are found in a wide range of such categories of classification. Some of them are viruses, some are bacteria, some are fungi, some are single-celled animals or protozoans. Some diseases are also caused by multicellular organisms, such as worms of different kinds.

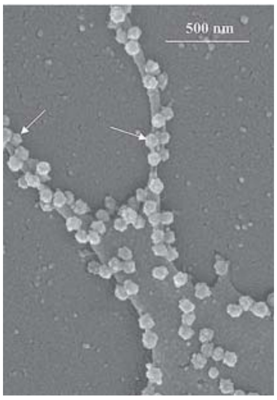


Fig. 13.1(a): *Picture of SARS viruses coming out (see arrows for examples) of the surface of an infected cell. The white scale line represents 500 nanometres, which is half a micrometre, which is one-thousandth of a millimetre. The scale line gives us an idea of how small the things we are looking at are.*
Courtesy: *Emerging Infectious Deseases, a journal of CDC, U.S.*

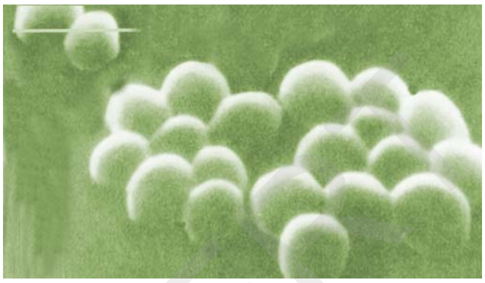


Fig. 13.1(b): *Picture of staphylococci, the bacteria which can cause acne. The scale of the image is indicated by the line at top left, which is 5 micrometres long.*

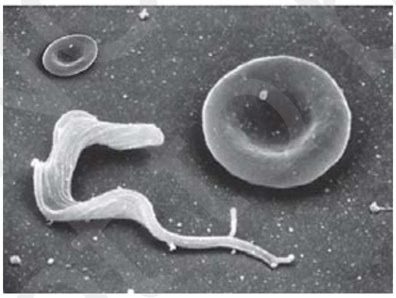


Fig. 13.1(c): *Picture of Trypanosoma, the protozoan organism responsible for sleeping sickness. The organism is lying next to a saucer-shaped red blood cell to give an idea of the scale.*
Copyright: *Oregon Health and Science University, U.S.*

Fig. 13.1(d): *Picture of Leishmania, the protozoan organism that causes kala-azar. The organisms are oval-shaped, and each has one long whip-like structure. One organism (arrow) is dividing, while a cell of the immune system (lower right) has gripped on the two whips of the dividing organism and is sending cell processes up to eat up the organism. The immune cell is about ten micrometres in diameter.*

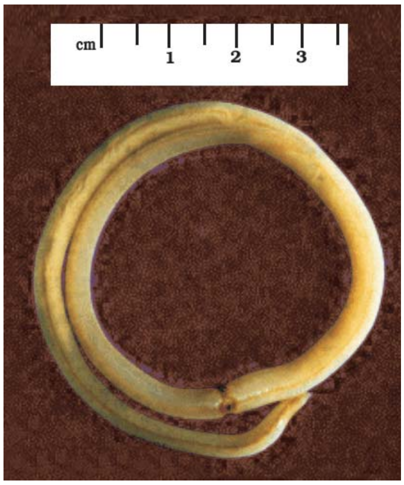


Fig. 13.1(e): *Picture of an adult roundworm (Ascaris lumbricoides is the technical name) from the small intestine. The ruler next to it shows four centimetres to give us an idea of the scale.*

Common examples of diseases caused by viruses are the common cold, influenza, dengue fever and AIDS. Diseases like typhoid fever, cholera, tuberculosis and anthrax are caused by bacteria. Many common skin infections are caused by different kinds of fungi. Protozoan microbes cause many familiar diseases, such as malaria and kala-azar. All of us have also come across intestinal worm infections, as well as diseases like elephantiasis caused by diffferent species of worms.

Why is it important that we think of these categories of infectious agents? The answer is that these categories are important factors in deciding what kind of treatment to use. Members of each one of these groups – viruses, bacteria, and so on – have many biological characteristics in common.

All viruses, for example, live inside host cells, whereas bacteria very rarely do. Viruses, bacteria and fungi multiply very quickly, while worms multiply very slowly in comparison. Taxonomically, all bacteria are closely related to each other than to viruses and vice versa. This means that many important life processes are similar in the bacteria group but are not shared with the virus group. As a result, drugs that block one of these life processes in one member of the group is likely to be effective against many other members of the group. But the same drug will not work against a microbe belonging to a different group.

As an example, let us take antibiotics. They commonly block biochemical pathways important for bacteria. Many bacteria, for example, make a cell-wall to protect themselves. The antibiotic penicillin blocks the bacterial processes that build the cell-wall. As a result, the growing bacteria become unable to make cell-walls, and die easily. Human cells don't make a cell-wall anyway, so penicillin cannot have such an effect on us. Penicillin will have this effect on any bacteria that use such processes for making cell-walls. Similarly, many antibiotics work against many species of bacteria rather than simply working against one.

But viruses do not use these pathways at all, and that is the reason why antibiotics do not work against viral infections. If we have a common cold, taking antibiotics does not reduce the severity or the duration of the disease. However, if we also get a bacterial infection along with the viral cold, taking antibiotics will help. Even then, the antibiotic will work only against the bacterial part of the infection, not the viral infection.

Activity 13.5

- Find out how many of you in your class had cold/cough/fever recently.
- How long did the illness last?
- How many of you took antibiotics (ask your parents if you had antibiotics)?
- How long were those who took antibiotics ill?
- How long were those who didn't take antibiotics ill?
- Is there a difference between these two groups?
- If yes, why? If not, why not?

13.3.2 Means of Spread

How do infectious diseases spread? Many microbial agents can commonly move from an affected person to someone else in a variety of ways. In other words, they can be 'communicated', and so are also called communicable diseases.

Such disease-causing microbes can spread through the air. This occurs through the little droplets thrown out by an infected person who sneezes or coughs. Someone standing close by can breathe in these droplets, and the microbes get a chance to start a new infection. Examples of such diseases spread through the air are the common cold, pneumonia and tuberculosis.

We all have had the experience of sitting near someone suffering from a cold and catching it ourselves. Obviously, the more crowded our living conditions are, the more likely it is that such airborne diseases will spread.

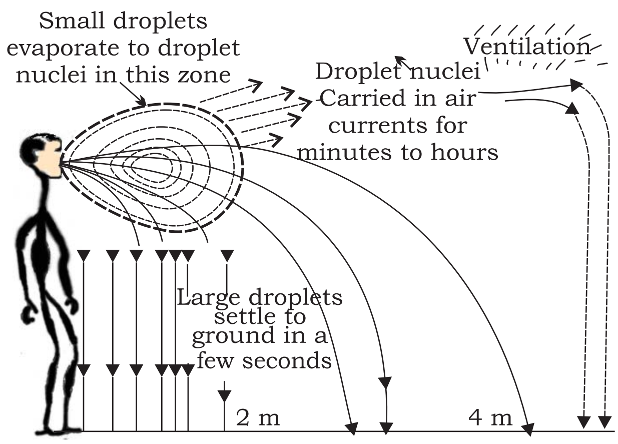


Fig. 13.2: *Air-transmitted diseases are easier to catch the closer we are to the infected person. However, in closed areas, the droplet nuclei recirculate and pose a risk to everybody. Overcrowded and poorly ventilated housing is therefore a major factor in the spread of airborne diseases.*

Diseases can also be spread through water. This occurs if the excreta from someone suffering from an infectious gut disease, such as cholera, get mixed with the drinking water used by people living nearby. The cholera-causing microbes will enter new hosts through the water they drink and cause disease in them. Such diseases are much more likely to spread in the absence of safe supplies of drinking water.

The sexual act is one of the closest physical contact two people can have with each other. Not surprisingly, there are microbial diseases such as syphilis or AIDS that are transmitted by sexual contact from one partner to the other. However, such sexually transmitted diseases are not spread by casual physical contact. Casual physical contacts include handshakes or hugs or sports, like wrestling, or by any of the other ways in which we touch each other socially. Other than the sexual contact, the AIDS virus can also spread through blood-to-blood contact with infected people or from an infected mother to her baby during pregnancy or through breast feeding.

We live in an environment that is full of many other creatures apart from us. It is inevitable that many diseases will be transmitted by other animals. These animals carry the infecting agents from a sick person to another potential host. These animals are thus the intermediaries and are called vectors. The commonest vectors we all know are mosquitoes. In many species of mosquitoes, the females need highly nutritious food in the form of blood in order to be able to lay mature eggs. Mosquitoes feed on many warm-blooded animals, including us. In this way, they can transfer diseases from person to person.

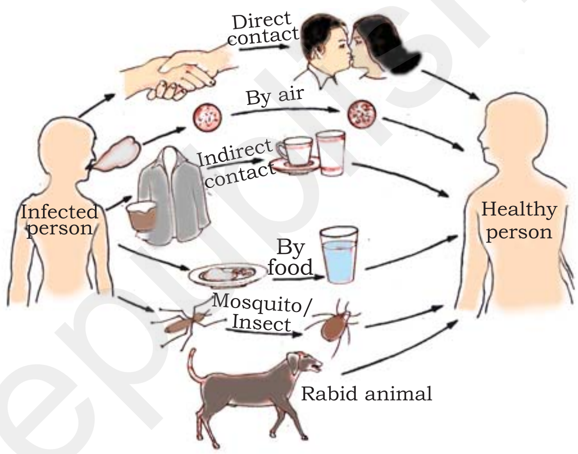


Fig. 13.3: *Common methods of transmission of diseases.*

13.3.3 ORGAN-SPECIFIC AND TISSUE-SPECIFIC MANIFESTATIONS

The disease-causing microbes enter the body through these different means. Where do they go then? The body is very large when compared to the microbes. So there are many possible places, organs or tissues, where they could go. Do all microbes go to the same tissue or organ, or do they go to different ones?

Different species of microbes seem to have evolved to home in on different parts of the body. In part, this selection is connected to their point of entry. If they enter from the air via the nose, they are likely to go to the lungs.

This is seen in the bacteria causing tuberculosis. If they enter through the mouth, they can stay in the gut lining like typhoid-causing bacteria. Or they can go to the liver, like the viruses that cause jaundice.

But this needn't always be the case. An infection like HIV, that comes into the body via the sexual organs, will spread to lymph nodes all over the body. Malaria-causing microbes, entering through a mosquito bite, will go to the liver, and then to the red blood cells. The virus causing Japanese encephalitis, or brain fever, will similarly enter through a mosquito bite. But it goes on to infect the brain.

The signs and symptoms of a disease will thus depend on the tissue or organ which the microbe targets. If the lungs are the targets, then symptoms will be cough and breathlessness. If the liver is targeted, there will be jaundice. If the brain is the target, we will observe headaches, vomiting, fits or unconsciousness. We can imagine what the symptoms and signs of an infection will be if we know what the target tissue or organ is, and the functions that are carried out by this tissue or organ.

In addition to these tissue-specific effects of infectious disease, there will be other common effects too. Most of these common effects depend on the fact that the body's immune system is activated in response to infection. An active immune system recruits many cells to the affected tissue to kill off the disease-causing microbes. This recruitment process is called inflammation. As a part of this process, there are local effects such as swelling and pain, and general effects such as fever.

In some cases, the tissue-specificity of the infection leads to very general-seeming effects. For example, in HIV infection, the virus goes to the immune system and damages its function. Thus, many of the effects of HIV-AIDS are because the body can no longer fight off the many minor infections that we face everyday. Instead, every small cold can become pneumonia. Similarly, a minor gut infection can produce major diarrhoea with blood loss. Ultimately, it is these other infections that kill people suffering from HIV-AIDS.

It is also important to remember that the severity of disease manifestations depend on the number of microbes in the body. If the number of microbes is very small, the disease manifestations may be minor or unnoticed. But if the number is of the same microbe large, the disease can be severe enough to be life-threatening. The immune system is a major factor that determines the number of microbes surviving in the body. We shall look into this aspect a little later in the chapter.

13.3.4 Principles of Treatment

What are the steps taken by your family when you fall sick? Have you ever thought why you sometimes feel better if you sleep for some time? When does the treatment involve medicines?

Based on what we have learnt so far, it would appear that there are two ways to treat an infectious disease. One would be to reduce the effects of the disease and the other to kill the cause of the disease. For the first, we can provide treatment that will reduce the symptoms. The symptoms are usually because of inflammation. For example, we can take medicines that bring down fever, reduce pain or loose motions. We can take bed rest so that we can conserve our energy. This will enable us to have more of it available to focus on healing.

But this kind of symptom-directed treatment by itself will not make the infecting microbe go away and the disease will not be cured. For that, we need to be able to kill off the microbes.

How do we kill microbes? One way is to use medicines that kill microbes. We have seen earlier that microbes can be classified into different categories. They are viruses, bacteria, fungi or protozoa. Each of these groups of organisms will have some essential biochemical life process which is peculiar to that group and not shared with the other groups. These processes may be pathways for the synthesis of new substances or respiration.

These pathways will not be used by us either. For example, our cells may make new substances by a mechanism different from that used by bacteria. We have to find a drug that blocks the bacterial synthesis pathway without affecting our own. This is what is achieved by the antibiotics that we are all familiar with. Similarly, there are drugs that kill protozoa such as the malarial parasite.

One reason why making anti-viral medicines is harder than making anti-bacterial medicines is that viruses have few biochemical mechanisms of their own. They enter our cells and use our machinery for their life processes. This means that there are relatively few virus-specific targets to aim at. Despite this limitation, there are now effective anti-viral drugs, for example, the drugs that keep HIV infection under control.

13.3.5 Principles of prevention

All of what we have talked about so far deals with how to get rid of an infection in someone who has the disease. But there are three limitations of this approach to dealing with infectious disease. The first is that once someone has a disease, their body functions are damaged and may never recover completely. The second is that treatment will take time, which means that someone suffering from a disease is likely to be bedridden for some time even if we can give proper treatment. The third is that the person suffering from an infectious disease can serve as the source from where the infection may spread to other people. This leads to the multiplication of the above difficulties. It is because of such reasons that prevention of diseases is better than their cure.

How can we prevent diseases? There are two ways, one general and one specific to each disease. The general ways of preventing infections mostly relate to preventing exposure. How can we prevent exposure to infectious microbes?

If we look at the means of their spreading, we can get some easy answers. For airborne microbes, we can prevent exposure by providing living conditions that are not overcrowded. For water-borne microbes, we can prevent exposure by providing safe drinking water. This can be done by treating the water to kill any microbial contamination. For vector-borne infections, we can provide clean environments. This would not, for example, allow mosquito breeding. In other words, public hygiene is one basic key to the prevention of infectious diseases.

In addition to these issues that relate to the environment, there are some other general principles to prevent infectious diseases. To appreciate those principles, let us ask a question we have not looked at so far. Normally, we are faced with infections everyday. If someone is suffering from a cold and cough in the class, it is likely that the children sitting around will be exposed to the infection. But all of them do not actually suffer from the disease. Why not?

This is because the immune system of our body is normally fighting off microbes. We have cells that specialise in killing infecting microbes. These cells go into action each time infecting microbes enter the body. If they are successful, we do not actually come down with any disease. The immune cells manage to kill off the infection long before it assumes major proportions. As we noted earlier, if the number of the infecting microbes is controlled, the manifestations of disease will be minor. In other words, becoming exposed to or infected with an infectious microbe does not necessarily mean developing noticeable disease.

So, one way of looking at severe infectious diseases is that it represents a lack of success of the immune system. The functioning of the immune system, like any other system in our body, will not be good if proper and sufficient nourishment and food is not available. Therefore, the second basic principle of prevention of infectious disease is the availability of proper and sufficient food for everyone.

Activity _____________ 13.6

- Conduct a survey in your locality. Talk to ten families who are well-off and ten who are very poor (in your estimation). Both sets of families should have children who are below five years of age. Measure the heights of these children. Draw a graph of the height of each child against its age for both sets of families.
- Is there a difference between the groups? If yes, why?
- If there is no difference, do you think that your findings mean that being well-off or poor does not matter for health?

These are the general ways of preventing infections. What are the specific ways? They relate to a peculiar property of the immune system that usually fights off microbial infections. Let us cite an example to try and understand this property.

These days, there is no smallpox anywhere in the world. But as recently as a hundred years ago, smallpox epidemics were not at all uncommon. In such an epidemic, people used to be very afraid of coming near someone suffering from the disease since they were afraid of catching the disease.

However, there was one group of people who did not have this fear. These people would provide nursing care for the victims of smallpox. This was a group of people who had had smallpox earlier and survived it, although with a lot of scarring. In other words, if you had smallpox once, there was no chance of suffering from it again. So, having the disease once was a means of preventing subsequent attacks of the same disease.

This happens because when the immune system first sees an infectious microbe, it responds against it and then remembers it specifically. So the next time that particular microbe, or its close relatives enter the body, the immune system responds with even greater vigour. This eliminates the infection even more quickly than the first time around. This is the basis of the principle of immunisation.

Immunisation

Traditional Indian and Chinese medicinal systems sometimes deliberately rubbed the skin crusts from smallpox victims into the skin of healthy people. They thus hoped to induce a mild form of smallpox that would create resistance against the disease.

Famously, two centuries ago, an English physician named Edward Jenner, realised that milkmaids who had had cowpox did not catch smallpox even during epidemics. Cowpox is a very mild disease. Jenner tried deliberately giving cowpox to people (as he can be seen doing in the picture), and found that they were now resistant to smallpox. This was because the smallpox virus is closely related to the cowpox virus. 'Cow' is 'vacca' in Latin, and cowpox is 'vaccinia'. From these roots, the word 'vaccination' has come into our usage.

We can now see that, as a general principle, we can 'fool' the immune system into developing a memory for a particular infection by putting something, that mimics the microbe we want to vaccinate against, into the body. This does not actually cause the disease but this would prevent any subsequent exposure to the infecting microbe from turning into actual disease.

Many such vaccines are now available for preventing a whole range of infectious diseases, and provide a disease-specific means of prevention. There are vaccines against tetanus, diphtheria, whooping cough, measles, polio and many others. These form the public health programme of childhood immunisation for preventing infectious diseases.

Of course, such a programme can be useful only if such health measures are available to all children. Can you think of reasons why this should be so?

Some hepatitis viruses, which cause jaundice, are transmitted through water. There is a vaccine for one of them, hepatitis A, in the market. But the majority of children in many parts of India are already immune to hepatitis A by the time they are five years old. This is because they are exposed to the virus through water. Under these circumstances, would you take the vaccine?

Activity 13.7

- Rabies virus is spread by the bite of infected dogs and other animals. There are anti-rabies vaccines for both humans and animals. Find out the plan of your local authority for the control of rabies in your neighbourhood. Are these measures adequate? If not, what improvements would you suggest?

Questions

1. *Why are we normally advised to take bland and nourishing food when we are sick?*
2. *What are the different means by which infectious diseases are spread?*
3. *What precautions can you take in your school to reduce the incidence of infectious diseases?*
4. *What is immunisation?*
5. *What are the immunisation programmes available at the nearest health centre in your locality? Which of these diseases are the major health problems in your area?*

What you have learnt

- Health is a state of physical, mental and social well-being.
- The health of an individual is dependent on his/her physical surroundings and his/her economic status.
- Diseases are classified as acute or chronic, depending on their duration.
- Disease may be due to infectious or non-infectious causes.
- Infectious agents belong to different categories of organisms and may be unicellular and microscopic or multicellular.
- The category to which a disease-causing organism belongs decides the type of treatment.
- Infectious agents are spread through air, water, physical contact or vectors.
- Prevention of disease is more desirable than its successful treatment.
- Infectious diseases can be prevented by public health hygiene measures that reduce exposure to infectious agents.

- Infectious diseases can also be prevented by using immunisation.
- Effective prevention of infectious diseases in the community requires that everyone should have access to public hygiene and immunisation.

Exercises

1. How many times did you fall ill in the last one year? What were the illnesses?
   (a) Think of one change you could make in your habits in order to avoid any of/most of the above illnesses.
   (b) Think of one change you would wish for in your surroundings in order to avoid any of/most of the above illnesses.
2. A doctor/nurse/health-worker is exposed to more sick people than others in the community. Find out how she/he avoids getting sick herself/himself.
3. Conduct a survey in your neighbourhood to find out what the three most common diseases are. Suggest three steps that could be taken by your local authorities to bring down the incidence of these diseases.
4. A baby is not able to tell her/his caretakers that she/he is sick. What would help us to find out
   (a) that the baby is sick?
   (b) what is the sickness?
5. Under which of the following conditions is a person most likely to fall sick?
   (a) when she is recovering from malaria.
   (b) when she has recovered from malaria and is taking care of someone suffering from chicken-pox.
   (c) when she is on a four-day fast after recovering from malaria and is taking care of someone suffering from chicken-pox.
   Why?
6. Under which of the following conditions are you most likely to fall sick?
   (a) when you are taking examinations.
   (b) when you have travelled by bus and train for two days.
   (c) when your friend is suffering from measles.
   Why?

Chapter 14

Natural Resources

Our planet, Earth is the only one on which life, as we know it, exists. Life on Earth is dependent on many factors. Most life-forms we know need an ambient temperature, water, and food. The resources available on the Earth and the energy from the Sun are necessary to meet the basic requirements of all life-forms on the Earth.

What are these resources on the Earth?

These are the land, the water and the air. The outer crust of the Earth is called the lithosphere. Water covers 75% of the Earth's surface. It is also found underground. These comprise the hydrosphere. The air that covers the whole of the Earth like a blanket, is called the atmosphere. Living things are found where these three exist. This life-supporting zone of the Earth where the atmosphere, the hydrosphere and the lithosphere interact and make life possible, is known as the biosphere.

Living things constitute the biotic component of the biosphere. The air, the water and the soil form the non-living or abiotic component of the biosphere. Let us study these abiotic components in detail in order to understand their role in sustaining life on Earth.

14.1 The Breath of Life: Air

We have already talked about the composition of air in the first chapter. It is a mixture of many gases like nitrogen, oxygen, carbon dioxide and water vapour. It is interesting to note that even the composition of air is the result of life on Earth. In planets such as Venus and Mars, where no life is known to exist, the major component of the atmosphere is found to be carbon dioxide. In fact, carbon dioxide constitutes up to 95-97% of the atmosphere on Venus and Mars.

Eukaryotic cells and many prokaryotic cells, discussed in Chapter 5, need oxygen to break down glucose molecules and get energy for their activities. This results in the production of carbon dioxide. Another process which results in the consumption of oxygen and the concomitant production of carbon dioxide is combustion. This includes not just human activities, which burn fuels to get energy, but also forest fires.

Despite this, the percentage of carbon dioxide in our atmosphere is a mere fraction of a percent because carbon dioxide is 'fixed' in two ways: (i) Green plants convert carbon dioxide into glucose in the presence of Sunlight and (ii) many marine animals use carbonates dissolved in sea-water to make their shells.

14.1.1 The Role of the Atmosphere in Climate Control

We have talked of the atmosphere covering the Earth, like a blanket. We know that air is a bad conductor of heat. The atmosphere keeps the average temperature of the Earth fairly steady during the day and even during the course of the whole year. The atmosphere prevents the sudden increase in temperature during the daylight hours. And during the night, it slows down the escape of heat into outer space. Think of the moon, which is about the same distance from the Sun that the Earth is. Despite that, on the surface of the moon, with no atmosphere, the temperature ranges from –190° C to 110° C.

Activity 14.1

- Measure the temperature of the following :
Take (i) a beaker full of water, (ii) a beaker full of soil/sand and (iii) a closed bottle containing a thermometer. Keep them in bright Sunlight for three hours. Now measure the temperature of all 3 vessels. Also, take the temperature reading in shade at the same time.

Now answer

1. *Is the temperature reading more in activity (i) or (ii)?*
2. *Based on the above finding, which would become hot faster – the land or the sea?*
3. *Is the thermometer reading of the temperature of air (in shade) the same as the temperature of sand or water? What do you think is the reason for this? And why does the temperature have to be measured in the shade?*
4. *Is the temperature of air in the closed glass vessel/bottle the same as the temperature taken in open air? (i) What do you think is the reason for this? (ii) Do we ever come across this phenomenon in daily life?*

As we have seen above, sand and water do not heat up at the same rate. What do you think will be their rates of cooling? Can we think of an experiment to test the prediction?

14.1.2 The Movement of Air: Winds

We have all felt the relief brought by cool evening breezes after a hot day. And sometimes, we are lucky enough to get rains after some days of really hot weather. What causes the movement of air, and what decides whether this movement will be in the form of a gentle breeze, a strong wind or a terrible storm? What brings us the welcome rains?

All these phenomena are the result of changes that take place in our atmosphere due to the heating of air and the formation of water vapour. Water vapour is formed due to the heating of water bodies and the activities of living organisms. The atmosphere can be heated from below by the radiation that is reflected back or re-radiated by the land or water bodies. On being heated, convection currents are set up in the air. In order to gain some understanding of the nature of convection currents, let us perform the following activity:

Activity 14.2

- Place a candle in a beaker or wide-mouthed bottle and light it. Light an incense stick and take it to the mouth of the above bottle (Figure 14.1).
- Which way does the smoke flow when the incense stick is kept near the edge of the mouth?
- Which way does the smoke flow when the incense stick is kept a little above the candle?
- Which way does the smoke flow when the incense stick is kept in other regions?

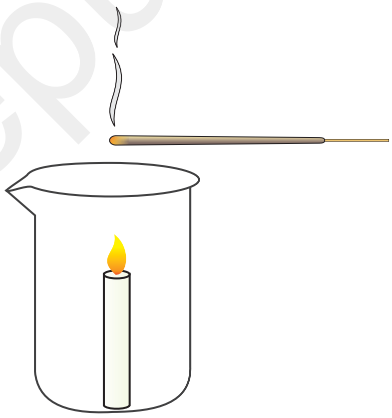


Fig. 14.1: *Air currents being caused by the uneven heating of air.*

The patterns revealed by the smoke show us the directions in which hot and cold air move. In a similar manner, when air is heated by radiation from the heated land or water, it rises. But since land gets heated faster than water, the air over land would also be heated faster than the air over water bodies.

So, if we look at the situation in coastal regions during the day, the air above the land gets heated faster and starts rising. As this air rises, a region of low pressure is created and air over the sea moves into this area of low pressure. The movement of air from one region to the other creates winds. During the day, the direction of the wind would be from the sea to the land.

At night, both land and sea start to cool. Since water cools down slower than the land, the air above water would be warmer than the air above land.

On the basis of the above discussion, what can you say about:

1. the appearance of areas of low and high pressure in coastal areas at night?
2. the direction in which air would flow at night in coastal areas?

Similarly, all the movements of air resulting in diverse atmospheric phenomena are caused by the uneven heating of the atmosphere in different regions of the Earth. But various other factors also influence these winds – the rotation of the Earth and the presence of mountain ranges in the paths of the wind are a couple of these factors. We will not go into these factors in detail in this chapter, but think about this: how do the presence of the Himalayas change the flow of a wind blowing from Allahabad towards the north?

14.1.3 Rain

Let us go back now to the question of how clouds are formed and bring us rain. We could start by doing a simple experiment which demonstrates some of the factors influencing these climatic changes.

Activity 14.3

- Take an empty bottle of the sort in which bottled water is sold. Pour about 5-10 mL of water into it and close the bottle tightly. Shake it well or leave it out in the Sun for ten minutes. This causes the air in the bottle to be saturated with water vapour.
- Now, take a lighted incense stick. Open the cap of the bottle and allow some of the smoke from the incense stick to enter the bottle. Quickly close the bottle once more. Make sure that the cap is fitting tightly. Press the bottle hard between your hands and crush it as much as possible. Wait for a few seconds and release the bottle. Again press the bottle as hard as you can.

Now answer

1. *When did you observe that the air inside seemed to become 'foggy'?*
2. *When does this fog disappear?*
3. *When is the pressure inside the bottle higher?*
4. *Is the 'fog' observed when the pressure in the bottle is high or when it is low?*
5. *What is the need for smoke particles inside the bottle for this experiment?*
6. *What might happen if you do the experiment without the smoke from the incense stick? Now try it and check if the prediction was correct. What might be happening in the above experiment in the absence of smoke particles?*

The above experiment replicates, on a very small scale, what happens when air with a very high content of water vapour goes from a region of high pressure to a region of low pressure or vice versa.

When water bodies are heated during the day, a large amount of water evaporates and goes into the air. Some amount of water vapour also get into the atmosphere because of various biological activities. This air also gets heated. The hot air rises up carrying the water vapour with it. As the air rises, it expands and cools. This cooling causes the water vapour in the air to condense in the form of tiny droplets. This condensation of water is facilitated if some particles could act as the 'nucleus' for these drops to form around. Normally dust and other suspended particles in the air perform this function.

Once the water droplets are formed, they grow bigger by the 'condensation' of these water droplets. When the drops have grown big and heavy, they fall down in the form of rain. Sometimes, when the temperature of air is low enough, precipitation may occur in the form of snow, sleet or hail.

Rainfall patterns are decided by the prevailing wind patterns. In large parts of India, rains are mostly brought by the south-west or north-east monsoons. We have also heard weather reports that say 'depressions' in the Bay of Bengal have caused rains in some areas (Figure 14.2).

Fig. 14.2: *Satellite picture showing clouds over India.*

Activity 14.4

- Collect information from newspapers or weather reports on television about rainfall patterns across the country. Also find out how to construct a rain-gauge and make one. What precautions are necessary in order to get reliable data from this rain-gauge? Now answer the following questions :
- In which month did your city/town/village get the maximum rainfall?
- In which month did your state/union territory get the maximum rainfall?
- Is rain always accompanied by thunder and lightning? If not, in which season do you get more of thunder and lightning with the rain?

Activity 14.5

- Find out more about monsoons and cyclones from the library. Try and find out the rainfall pattern of any other country. Is the monsoon responsible for rains the world over?

14.1.4 Air Pollution

We keep hearing of the increasing levels of oxides of nitrogen and sulphur in the news. People often bemoan the fact that the quality of air has gone down since their childhood. How is the quality of air affected and how does this change in quality affect us and other life forms?

The fossil fuels like coal and petroleum contain small amounts of nitrogen and sulphur. When these fuels are burnt, nitrogen and sulphur too are burnt and this produces different oxides of nitrogen and sulphur. Not only is the inhalation of these gases dangerous, they also dissolve in rain to give rise to acid rain. The combustion of fossil fuels also increases the amount of suspended particles in air. These suspended particles could be unburnt carbon particles or substances called hydrocarbons. Presence of high levels of all these pollutants cause visibility to be lowered, especially in cold weather when water also condenses out of air. This is known as smog and is a visible indication of air pollution. Studies have shown that regularly breathing air that contains any of these substances increases the incidence of allergies, cancer and heart diseases. An increase in the content of these harmful substances in air is called air pollution.

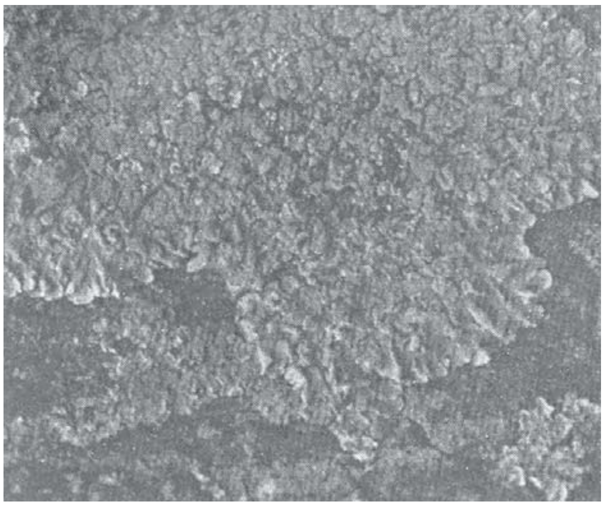


Fig. 14.3: *Lichen*

Activity 14.6

- Organisms called lichens are found to be very sensitive to the levels of contaminants like sulphur dioxide in the air. As discussed earlier in section 7.3.3, lichens can be commonly found growing on the barks of trees as a thin greenish-white crust. See if you can find lichen growing on the trees in your locality.
- Compare the lichen on trees near busy roads and trees some distance away.
- On the trees near roads, compare the incidence of lichen on the side facing the road and on the side away from the road.

What can you say about the levels of polluting substances near roads and away from roads on the basis of your findings above?

Questions

1. *How is our atmosphere different from the atmospheres on Venus and Mars?*
2. *How does the atmosphere act as a blanket?*
3. *What causes winds?*
4. *How are clouds formed?*
5. *List any three human activities that you think would lead to air pollution.*

14.2 Water: A Wonder Liquid

Water occupies a very large area of the Earth's surface and is also found underground. Some amount of water exists in the form of water vapour in the atmosphere. Most of the water on Earth's surface is found in seas and oceans and is saline. Fresh water is found frozen in the ice-caps at the two poles and on snow-covered mountains. The underground water and the water in rivers, lakes and ponds is also fresh. However, the availability of fresh water varies from place to place. Practically every summer, most places have to face a shortage of water. And in rural areas, where water supply systems have not been installed, people are forced to spend considerable amounts of time in fetching water from far-away sources.

Activity 14.7

- Many municipal corporations are trying water-harvesting techniques to improve the availability of water.
- Find out what these techniques are and how they would increase the water that is available for use.

But why is water so necessary? And do all organisms require water? All cellular processes take place in a water medium. All the reactions that take place within our body and within the cells occur between substances that are dissolved in water. Substances are also transported from one part of the body to the other in a dissolved form. Hence, organisms need to maintain the level of water within their bodies in order to stay alive. Terrestrial life-forms require fresh water for this because their bodies cannot tolerate or get rid of the high amounts of dissolved salts in saline water. Thus, water sources need to be easily accessible for animals and plants to survive on land.

Activity 14.8

- Select a small area (say, 1 m^2) near a water-body, it may be a river, stream, lake or pond. Count the number of different animals and plants in this area. Also, check the number of individuals of each type or species.
- Compare this with the number of individuals (both animals and plants) found in an area of the same size in a dry, rocky region.
- Is the variety of plant and animal life the same in both these areas?

Activity 14.9

- Select and mark out a small area (about 1 m^2) in some unused land in or near your school.
- As in the above activity, count the number of different animals and plants in this area and the number of individuals of each species.

- Remember to do this in the same place twice in a year, once during summer or the dry season and once after it has rained.

Now answer

1. *Were the numbers similar both times?*
2. *In which season did you find more variety of plants and animals?*
3. *In which season did you find more number of individuals of each variety?*

After compiling the results of the above two activities, think if there is any relationship between the amount of available water and the number and variety of plants and animals that can live in a given area. If there is a relationship, where do you think you would find a greater variety and abundance of life – in a region that receives 5 cm of rainfall in a year or a region that receives 200 cm of rainfall in a year? Find the map showing rainfall patterns in the atlas and predict which States in India would have the maximum biodiversity and which would have the least. Can we think of any way of checking whether the prediction is correct?

The availability of water decides not only the number of individuals of each species that are able to survive in a particular area, but it also decides the diversity of life there. Of course, the availability of water is not the only factor that decides the sustainability of life in a region. Other factors like the temperature and nature of soil also matter. But water is one of the major resources which determine life on land.

14.2.1 Water Pollution

Water dissolves the fertilisers and pesticides that we use on our farms. So some percentage of these substances are washed into the water bodies. Sewage from our towns and cities and the waste from factories are also dumped into rivers or lakes. Specific industries also use water for cooling in various operations and later return this hot water to water-bodies. Another manner in which the temperature of the water in rivers can be affected is when water is released from dams. The water inside the deep reservoir would be colder than the water at the surface which gets heated by the Sun.

All this can affect the life-forms that are found in these water bodies in various ways. It can encourage the growth of some life-forms and harm some other life-forms. This affects the balance between various organisms which had been established in that system. So we use the term water-pollution to cover the following effects:

1. The addition of undesirable substances to water-bodies. These substances could be the fertilisers and pesticides used in farming or they could be poisonous substances, like mercury salts which are used by paper-industries. These could also be disease-causing organisms, like the bacteria which cause cholera.
2. The removal of desirable substances from water-bodies. Dissolved oxygen is used by the animals and plants that live in water. Any change that reduces the amount of this dissolved oxygen would adversely affect these aquatic organisms. Other nutrients could also be depleted from the water bodies.
3. A change in temperature. Aquatic organisms are used to a certain range of temperature in the water-body where they live, and a sudden marked change in this temperature would be dangerous for them or affect their breeding. The eggs and larvae of various animals are particularly susceptible to temperature changes.

Questions

1. *Why do organisms need water?*
2. *What is the major source of fresh water in the city/town/village where you live?*
3. *Do you know of any activity which may be polluting this water source?*

14.3 Mineral Riches in the Soil

Soil is an important resource that decides the diversity of life in an area. But what is the soil and how is it formed? The outermost layer of our Earth is called the crust and the minerals found in this layer supply a variety of nutrients to life-forms. But these minerals will not be available to the organisms if the minerals are bound up in huge rocks. Over long periods of time, thousands and millions of years, the rocks at or near the surface of the Earth are broken down by various physical, chemical and some biological processes. The end product of this breaking down is the fine particles of soil. But what are the factors or processes that make soil?

- The Sun: The Sun heats up rocks during the day so that they expand. At night, these rocks cool down and contract. Since all parts of the rock do not expand and contract at the same rate, this results in the formation of cracks and ultimately the huge rocks break up into smaller pieces.
- Water: Water helps in the formation of soil in two ways. One, water could get into the cracks in the rocks formed due to uneven heating by the Sun. If this water later freezes, it would cause the cracks to widen. Can you think why this should be so? Two, flowing water wears away even hard rock over long periods of time. Fast flowing water often carries big and small particles of rock downstream. These rocks rub against other rocks and the resultant abrasion causes the rocks to wear down into smaller and smaller particles. The water then takes these particles along with it and deposits it further down its path. Soil is thus found in places far away from its parent-rock.
- Wind: In a process similar to the way in which water rubs against rocks and wears them down, strong winds also erode rocks down. The wind also carries sand from one place to the other like water does.
- Living organisms also influence the formation of soil. The lichen that we read about earlier, also grows on the surface of rocks. While growing, they release certain substances that cause the rock surface to powder down and form a thin layer of soil. Other small plants like moss, are able to grow on this surface now and they cause the rock to break up further. The roots of big trees sometimes go into cracks in the rocks and as the roots grow bigger, the crack is forced bigger.

Activity 14.10

- Take some soil and put it into a beaker containing water. The water should be at least five times the amount of soil taken. Stir the soil and water vigorously and allow the soil to settle down. Observe after some time.
- Is the soil at the bottom of the beaker homogenous or have layers formed?
- If layers have formed, how is one layer different from another?
- Is there anything floating on the surface of the water?
- Do you think some substances would have dissolved in the water? How would you check?

As you have seen, soil is a mixture. It contains small particles of rock (of different sizes). It also contains bits of decayed living organisms which is called humus. In addition, soil also contains various forms of microscopic life. The type of soil is decided by the average size of particles found in it and the quality of the soil is decided by the amount of humus and the microscopic organisms found in it. Humus is a major factor in deciding the soil structure because it causes the soil to become more porous and allows water and air to penetrate deep underground. The mineral nutrients that are found in a particular soil depends on the rocks it was formed from. The nutrient content of a soil, the amount of humus present in it and the depth of the soil are some of the factors that decide which plants will thrive on that soil. Thus, the topmost layer of the soil that contains humus and living organisms in addition to the soil particles is called the topsoil. The quality of the topsoil is an important factor that decides biodiversity in that area.

Modern farming practices involve the use of large amounts of fertilizers and pesticides. Use of these substances over long periods of time can destroy the soil structure by killing the soil micro-organisms that recycle nutrients in the soil. It also kills the Earthworms which are instrumental in making the rich humus. Fertile soil can quickly be turned barren if sustainable practices are not followed. Removal of useful components from the soil and addition of other substances, which adversely affect the fertility of the soil and kill the diversity of organisms that live in it, is called soil pollution.

The soil that we see today in one place has been created over a very long period of time. However, some of the factors that created the soil in the first place and brought the soil to that place may be responsible for the removal of the soil too. The fine particles of soil may be carried away by flowing water or wind. If all the soil gets washed away and the rocks underneath are exposed, we have lost a valuable resource because very little will grow on the rock.

Activity 14.11

- Take two identical trays and fill them with soil. Plant mustard or green gram or paddy in one of the trays and water both the trays regularly for a few days, till the first tray is covered by plant growth. Now, tilt both the trays and fix them in that position. Make sure that both the trays are tilted at the same angle. Pour equal amount of water gently on both trays such that the water flows out of the trays (Fig. 14.4).
- Study the amount of soil that is carried out of the trays. Is the amount the same in both the trays?
- Now pour equal amounts of water on both the trays from a height. Pour three or four times the amount that you poured earlier.
- Study the amount of soil that is carried out of the trays now. Is the amount the same in both the trays?
- Is the amount of soil that is carried out more or less or equal to the amount washed out earlier?

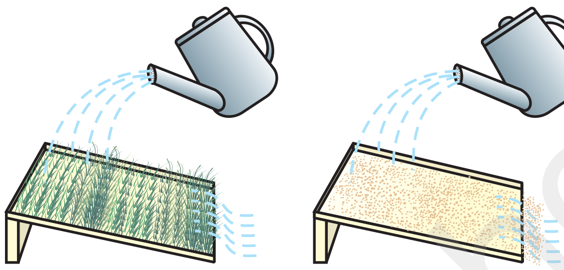


Fig. 14.4: *Effect of flowing water on the top-soil*

The roots of plants have an important role in preventing soil erosion. The large-scale deforestation that is happening all over the world not only destroys biodiversity, it also leads to soil erosion. Topsoil that is bare of vegetation, is likely to be removed very quickly. And this is accelerated in hilly or mountainous regions. This process of soil erosion is very difficult to reverse. Vegetative cover on the ground has a role to play in the percolation of water into the deeper layers too.

Questions

1. *How is soil formed?*
2. *What is soil erosion?*
3. *What are the methods of preventing or reducing soil erosion?*

14.4 Biogeochemical Cycles

A constant interaction between the biotic and abiotic components of the biosphere makes it a dynamic, but stable system. These interactions consist of a transfer of matter and energy between the different components of the biosphere. Let us look at some processes involved in the maintenance of the above balance.

14.4.1 The Water-Cycle

You have seen how the water evaporates from the water bodies and subsequent condensation of this water vapour leads to rain. But we don't see the seas and oceans drying up. So, how is the water returning to these water bodies? The whole process in which water evaporates and falls on the land as rain and later flows back into the sea via rivers is known as the water-cycle. This cycle is not as straight-forward and simple as this statement seems to imply. All of the water that falls on the land does not immediately flow back into the sea. Some of it seeps into the soil and becomes part of the underground reservoir of fresh-water. Some of this underground water finds its way to the surface through springs. Or we bring it to the surface for our use through wells or tube-wells. Water is also used by terrestrial animals and plants for various life-processes (Fig. 14.5).

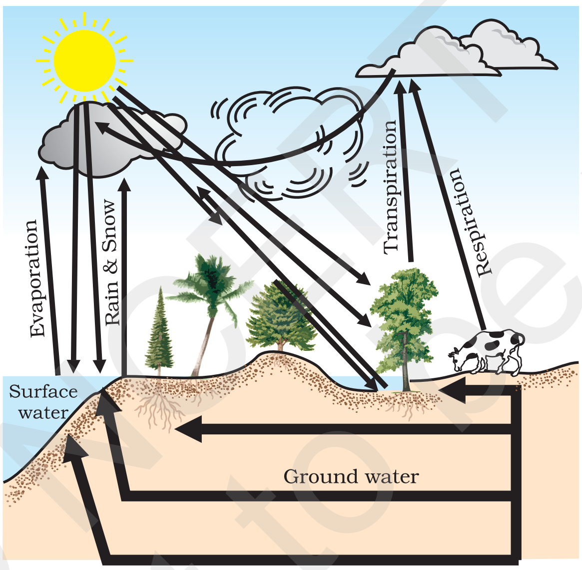


Fig. 14.5: *Water-cycle in nature*

Let us look at another aspect of what happens to water during the water-cycle. As you know, water is capable of dissolving a large number of substances. As water flows through or over rocks containing soluble minerals, some of them get dissolved in the water. Thus rivers carry many nutrients from the land to the sea, and these are used by the marine organisms.

14.4.2 The Nitrogen-Cycle

Nitrogen gas makes up 78% of our atmosphere and nitrogen is also a part of many molecules essential to life like proteins, nucleic acids (DNA and RNA) and some vitamins. Nitrogen is found in other biologically important compounds such as alkaloids and urea too. Nitrogen is thus an essential nutrient for all life-forms and life would be simple if all these life-forms could use the atmospheric nitrogen directly. However, other than a few forms of bacteria, life-forms are not able to convert the comparatively inert nitrogen molecule into forms like nitrates and nitrites which can be taken up and used to make the required molecules. These 'nitrogen-fixing' bacteria may be free-living or be associated with some species of dicot plants. Most commonly, the nitrogen-fixing bacteria are found in the roots of legumes (generally the plants which give us pulses) in special structures called root-nodules. Other than these bacteria, the only other manner in which the nitrogen molecule is converted to nitrates and nitrites is by a physical process. During lightning, the high temperatures and pressures created in the air convert nitrogen into oxides of nitrogen. These oxides dissolve in water to give nitric and nitrous acids and fall on land along with rain. These are then utilised by various life-forms.

What happens to the nitrogen once it is converted into forms that can be taken up and used to make nitrogen-containing molecules? Plants generally take up nitrates and nitrites and convert them into amino acids which are used to make proteins. Some other biochemical pathways are used to make the other complex compounds containing nitrogen. These proteins and other complex compounds are subsequently consumed by animals. Once the animal or the plant dies, other bacteria in the soil convert the various compounds of nitrogen back into nitrates and

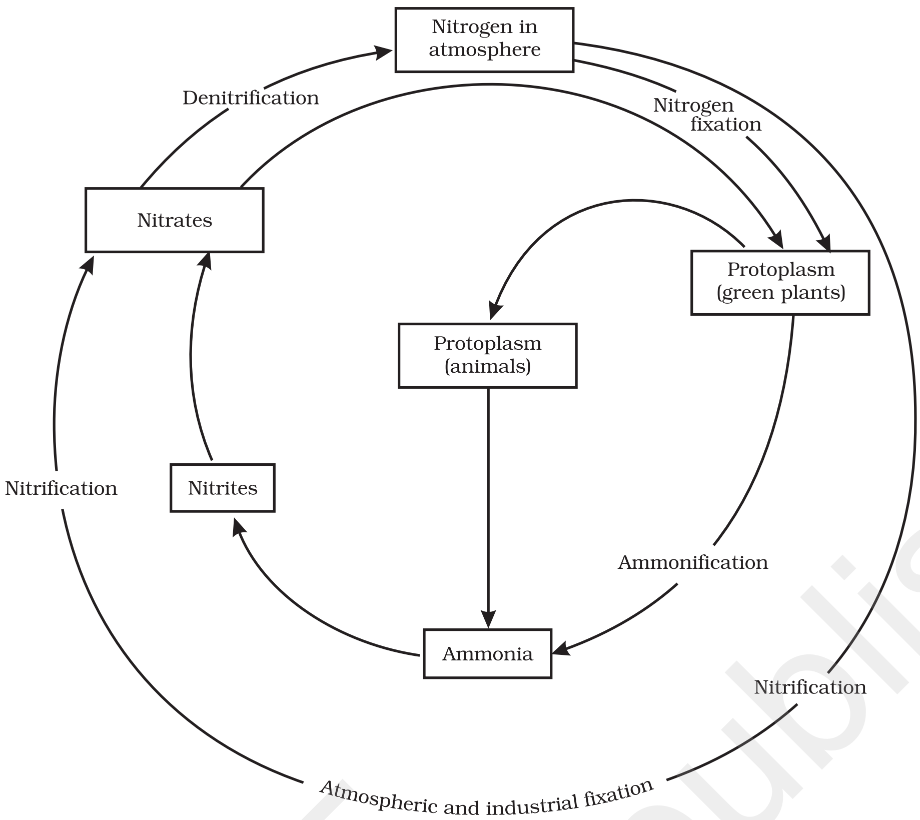


Fig.14.6: *Nitrogen-cycle in nature*

nitrites. A different type of bacteria converts the nitrates and nitrites into elemental nitrogen. Thus, there is a nitrogen-cycle in nature in which nitrogen passes from its elemental form in the atmosphere into simple molecules in the soil and water, which get converted to more complex molecules in living beings and back again to the simple nitrogen molecule in the atmosphere.

14.4.3 The carbon-cycle

Carbon is found in various forms on the Earth. It occurs in the elemental form as diamonds and graphite. In the combined state, it is found as carbon dioxide in the atmosphere, as carbonate and hydrogen-carbonate salts in various minerals, while all life-forms are based on carbon-containing molecules like proteins, carbohydrates, fats, nucleic acids and vitamins. The endoskeletons and exoskeletons of various animals are also formed from carbonate salts. Carbon is incorporated into life-forms through the basic process of photosynthesis which is performed in the presence of Sunlight by all life-forms that contain chlorophyll. This process converts carbon dioxide from the atmosphere or dissolved in water into glucose molecules. These glucose molecules are either converted into other substances or used to provide energy for the synthesis of other biologically important molecules (Fig. 14.7).

The utilisation of glucose to provide energy to living things involves the process of respiration in which oxygen may or may not be used to convert glucose back into carbon dioxide. This carbon dioxide then goes back into the atmosphere. Another process that

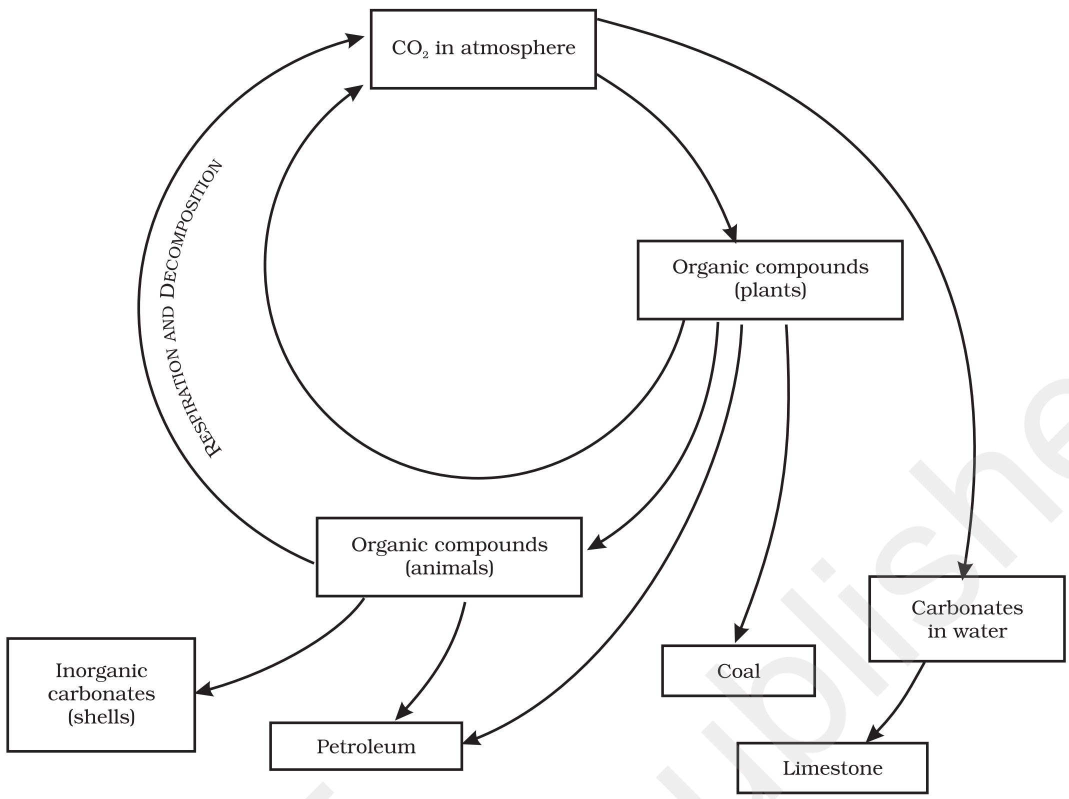


Fig. 14.7: *Carbon-cycle in nature*

adds to the carbon dioxide in the atmosphere is the process of combustion where fuels are burnt to provide energy for various needs like heating, cooking, transportation and industrial processes. In fact, the percentage of carbon dioxide in the atmosphere is said to have doubled since the industrial revolution when human beings started burning fossil fuels on a very large scale. Carbon, like water, is thus cycled repeatedly through different forms by the various physical and biological activities.

14.4.3 (i) The Greenhouse Effect

Recall the reading taken by you under (iii) in Activity 14.1. Heat is trapped by glass, and hence the temperature inside a glass enclosure will be much higher than the surroundings. This phenomenon was used to create an enclosure where tropical plants could be kept warm during the winters in colder climates. Such enclosures are called greenhouses. Greenhouses have also lent their name to an atmospheric phenomenon. Some gases prevent the escape of heat from the Earth. An increase in the percentage of such gases in the atmosphere would cause the average temperatures to increase worldwide and this is called the greenhouse effect. Carbon dioxide is one of the greenhouse gases. An increase in the carbon dioxide content in the atmosphere would cause more heat to be retained by the atmosphere and lead to global warming.

Activity 14.12

- Find out what the consequences of global warming would be.
- Also, find out the names of some other greenhouse gases.

14.4.4 THE OXYGEN-CYCLE

Oxygen is a very abundant element on our Earth. It is found in the elemental form in the atmosphere to the extent of 21%. It also occurs extensively in the combined form in the Earth's crust as well as also in the air in the form of carbon dioxide. In the crust, it is found as the oxides of most metals and silicon, and also as carbonate, sulphate, nitrate and other minerals. It is also an essential component of most biological molecules like carbohydrates, proteins, nucleic acids and fats (or lipids).

But when we talk of the oxygen-cycle, we are mainly referring to the cycle that maintains the levels of oxygen in the atmosphere. Oxygen from the atmosphere is used up in three processes, namely combustion, respiration and in the formation of oxides of nitrogen. Oxygen is returned to the atmosphere in only one major process, that is, photosynthesis. And this forms the broad outline of the oxygen-cycle in nature (Fig. 14.8).

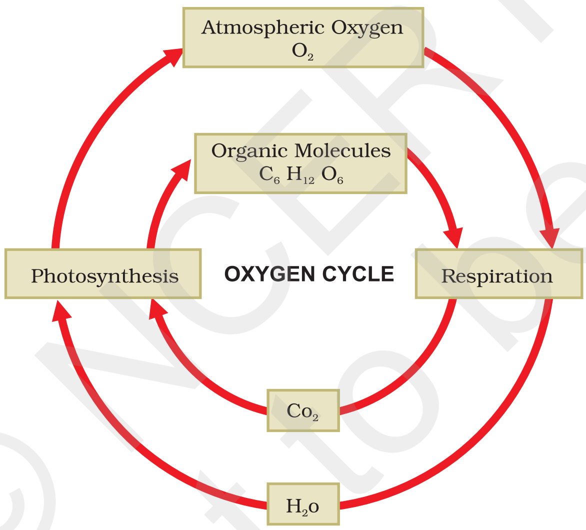


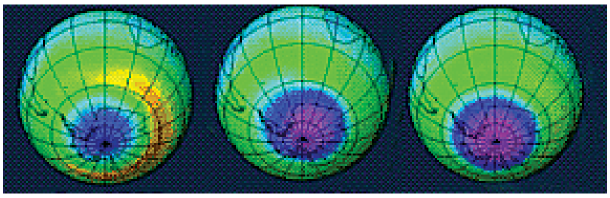
Fig. 14.8: *Oxygen-cycle in nature*

Though we usually think of oxygen as being necessary to life in the process of respiration, it might be of interest to you to learn that some forms of life, especially bacteria, are poisoned by elemental oxygen. In fact, even the process of nitrogen-fixing by bacteria does not take place in the presence of oxygen.

14.5 Ozone Layer

Elemental oxygen is normally found in the form of a diatomic molecule. However, in the upper reaches of the atmosphere, a molecule containing three atoms of oxygen is found. This would mean a formula of O_3 and this is called ozone. Unlike the normal diatomic molecule of oxygen, ozone is poisonous and we are lucky that it is not stable nearer to the Earth's surface. But it performs an essential function where it is found. It absorbs harmful radiations from the Sun. This prevents those harmful radiations from reaching the surface of the Earth where they may damage many forms of life.

Recently it was discovered that this ozone layer was getting depleted. Various man-made compounds like CFCs (carbon compounds having both fluorine and chlorine which are very stable and not degraded by any biological process) were found to persist in the atmosphere. Once they reached the ozone layer, they would react with the ozone molecules. This resulted in a reduction of the ozone layer and recently they have discovered a hole in the ozone layer above the Antartica. It is difficult to imagine the consequences for life on Earth if the ozone layer dwindles further, but many people think that it would be better not to take chances. These people advocate working towards stopping all further damage to the ozone layer.



October 1980	October 1985	October 1990

Fig. 14.9: *Satellite picture showing the hole (magenta colour) in the ozone layer over Antartica*

Activity ______________ 14.13

- Find out which other molecules are thought to damage the ozone layer.
- Newspaper reports often talk about the hole in the ozone layer.
- Find out whether the size of this hole is changing and in what manner scientists think this would affect life on Earth (Fig. 14.9).

Questions

1. *What are the different states in which water is found during the water cycle?*
2. *Name two biologically important compounds that contain both oxygen and nitrogen.*
3. *List any three human activities which would lead to an increase in the carbon dioxide content of air.*
4. *What is the greenhouse effect?*
5. *What are the two forms of oxygen found in the atmosphere?*

What you have learnt

- Life on Earth depends on resources like soil, water and air, and energy from the Sun.
- Uneven heating of air over land and water-bodies causes winds.
- Evaporation of water from water-bodies and subsequent condensation give us rain.
- Rainfall patterns depend on the prevailing wind patterns in an area.
- Various nutrients are used again and again in a cyclic fashion. This leads to a certain balance between the various components of the biosphere.
- Pollution of air, water and soil affect the quality of life and harm the biodiversity.
- We need to conserve our natural resources and use them in a sustainable manner.

Exercises

1. Why is the atmosphere essential for life?
2. Why is water essential for life?
3. How are living organisms dependent on the soil? Are organisms that live in water totally independent of soil as a resource?
4. You have seen weather reports on television and in newspapers. How do you think we are able to predict the weather?

5. We know that many human activities lead to increasing levels of pollution of the air, water-bodies and soil. Do you think that isolating these activities to specific and limited areas would help in reducing pollution?
6. Write a note on how forests influence the quality of our air, soil and water resources.

Answers

Chapter 3

4. (a) $MgCl_2$
   (b) CaO
   (c) $Cu\ (NO_3)_2$
   (d) $AlCl_3$
   (e) $CaCO_3$
5. (a) Calcium, oxygen
   (b) Hydrogen, bromine
   (c) Sodium, hydrogen, carbon and oxygen
   (d) Potassium, sulphur and oxygen
6. (a) 26 g
   (b) 256 g
   (c) 124 g
   (d) 36.5 g
   (e) 63 g
7. (a) 14 g
   (b) 108 g
   (c) 1260 g
8. (a) 0.375 mole
   (b) 1.11 mole
   (c) 0.5 mole
9. (a) 3.2 g
   (b) 9.0 g
10. 3.76×10^{22} molecules
11. 6.022×10^{20} ions

Chapter 4

10. 80.006
11. ${}^{16}_{8}\times = 90\%$, ${}^{18}_{8}\times = 10\%$
12. Valency = 1, Name of the element is lithium,
13. Mass number of X =12, Y=14, Relationship is Isotope.

14.	(a) F	(b) F	(c) T	(d) F
15.	(a) ✓	(b) ×	(c) ×	(d) ×
16.	(a) ×	(b) ×	(c) ✓	(d) ×

17. (a) × (b) ✓ (c) × (d) ×

18. (a) × (b) × (c) × (d) ✓

19.

Atomic Number	Mass Number	Number of Neutrons	Number of Protons	Number of Electrons	Name of the Atomic Species
9	19	10	9	9	Fluorine
16	32	16	16	16	Sulphur
12	24	12	12	12	Magnesium
01	2	01	1	01	Deuterium
01	1	0	1	0	Protium

Chapter 8

1. (a) distance = 2200 m; displacement = 200 m.
2. (a) average speed = average velocity = 2.00 m s^{-1}
   (b) average speed = 1.90 m s^{-1}; average velocity = 0.952 m s^{-1}
3. average speed = 24 km h^{-1}
4. distance travelled = 96 m
7. velocity = 20 m s^{-1}; time = 2 s
10. speed = 3.07 km s^{-1}

Chapter 9

4. c
5. 14000 N
6. – 4 N
7. (a) 35000 N
   (b) 1.944 m s^{-2}
   (c) 15556 N
8. 2550 N in a direction opposite to the motion of the vehicle
9. d
10. 200 N
11. 0 m s^{-1}
13. 3 kg m s^{-1}
14. 2.25 m; 50 N
15. 10 kg m s^{-1}; 10 kg m s^{-1}; 5/3 m s^{-1}
16. 500 kg m s^{-1}; 800 kg m s^{-1}; 50 N
18. 40 kg m s^{-1}

A2. 240 N

A3. 2500 N

A4. 5 m s^{-2}; 2400 kg m s^{-1}; 6000 N

Chapter 10

3. 9.8 N
12. Weight on earth is 98 N and on moon is 16.3 N.
13. Maximum height is 122.5 m and total time is 5 s + 5 s = 10 s.
14. 19.6 m/s
15. Maximum height = 80 m, Net displacement = 0, Total distance covered = 160 m.
16. Gravitational force = 3.56×10^{22} N.
17. 4 s, 80 m from the top.
18. Initial velocity = 29.4 m s^{-1}, height = 44.1 m. After 4 s the ball will be at a distance of 4.9 m from the top or 39.2 m from the bottom.
21. The substance will sink.
22. The packet will sink. The mass of water displaced is 350 g.

Chapter 11

2. Zero
4. 210 J
5. Zero
9. 9×10^8 J
10. 2000 J, 1000 J
11. Zero
14. 15 kWh (Unit)
17. 208333.3 J
18. (i) Zero
    (ii) Positive
    (iii) Negative
20. 20 kWh

Chapter 12

7. 17.2 m, 0.0172 m
8. 18.55
9. 6000
13. 11.47 s
14. 22,600 Hz
20. 1450 ms^{-1}