South Sudan

Secondary Biology 4

Student's Book

Secondary Biology has been written and developed by Ministry of General Education and Instruction, Government of South Sudan in conjunction with Subjects experts. This course book provides a fun and practical approach to the subject of Biology, and at the same time imparting life long skills to the students.

The book comprehensively covers the Secondary 4 syllabus as developed by Ministry of General Education and Instruction.

Each year comprises of a Student's Book and Teacher's Guide

The Student's Books provide:

- Full coverage of the national syllabus.
- A strong grounding in the basics of Biology.
- Clear presentation and explanation of learning points.
- A wide variety of practice exercises, often showing how Biology can be applied to real-life situations.
- It provides opportunities for collaboration through group work activities.
- Stimulating illustrations.

All the courses in this secondary series were developed by the Ministry of General Education and Instruction, Republic of South Sudan. The books have been designed to meet the secondary school syllabus, and at the same time equiping the students with skills to fit in the modern day global society.

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Secondary Biology 4 Student's Book

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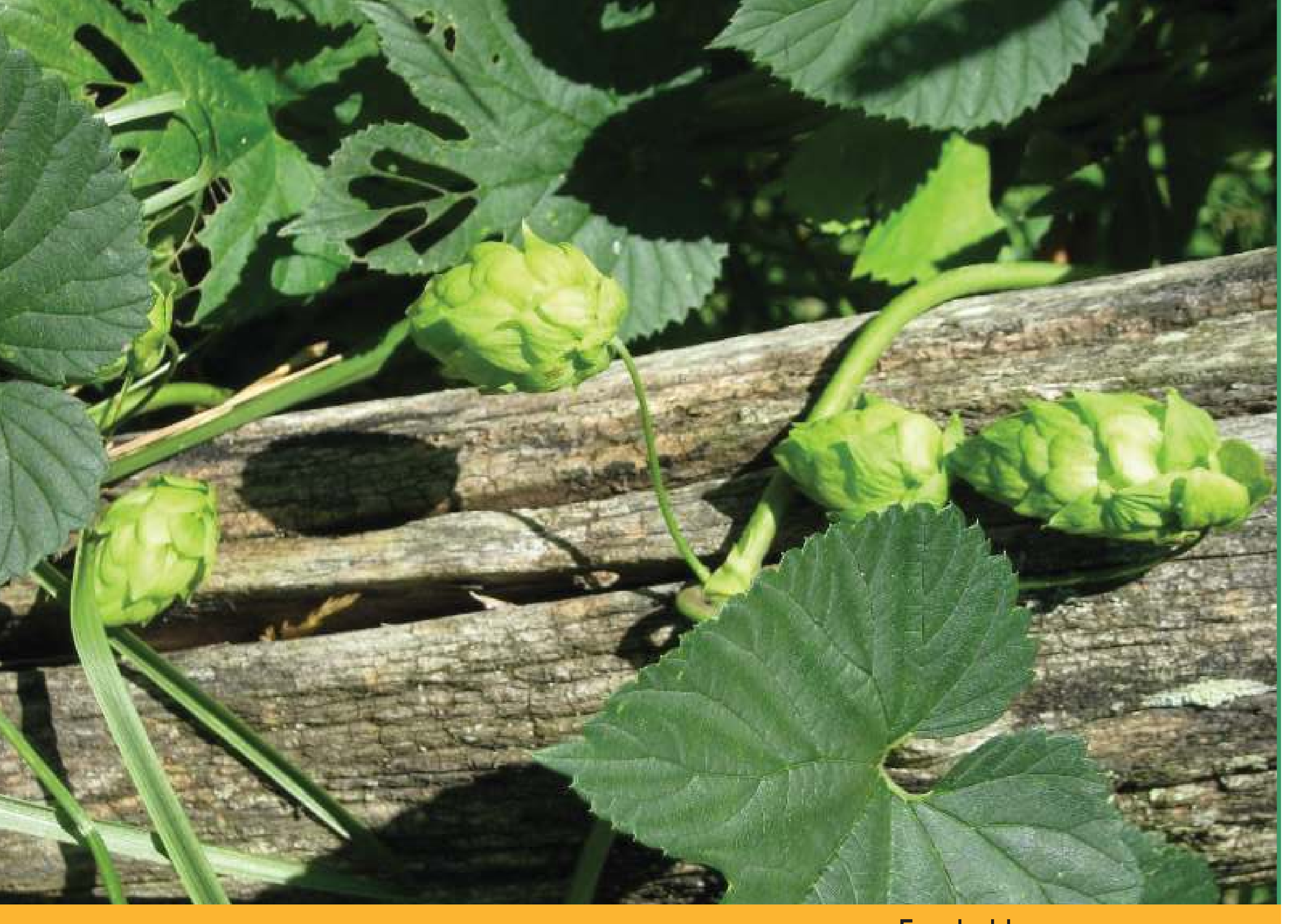

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South Sudan

SECONDARY
4

Biology

Student's Book

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FOREWORD

I am delighted to present to you this textbook, which is developed by the Ministry of General Education and Instruction based on the new South Sudan National Curriculum. The National Curriculum is a learner-centered curriculum that aims to meet the needs and aspirations of the new nation. In particular, it aims to develop (a) Good citizens; (b) successful lifelong learners; (c) creative, active and productive individuals; and (d) Environmentally responsible members of our society. This textbook, like many others, has been designed to contribute to achievement of these noble aims. It has been revised thoroughly by our Subject Panels, is deemed to be fit for the purpose and has been recommended to me for approval. Therefore, I hereby grant my approval. This textbook shall be used to facilitate learning for learners in all schools of the Republic of South Sudan, except international schools, with effect from 4th February, 2019.

I am deeply grateful to the staff of the Ministry of General Education and Instruction, especially Mr Michael Lopuke Lotyam Longolio, the Undersecretary of the Ministry, the staff of the Curriculum Development Centre, under the supervision of Mr Omot Okony Olok, the Director General for Quality Assurance and Standards, the Subject Panelists, the Curriculum Foundation (UK), under the able leadership of Dr Brian Male, for providing professional guidance throughout the process of the development of National Curriculum and school textbooks for the Republic of South Sudan since 2013. I wish to thank UNICEF South Sudan for managing the project funded by the Global Partnership in Education so well and funding the development of the National Curriculum and the new textbooks. I am equally grateful for the support provided by Mr Tony Calderbank, the former Country Director of the British Council, South Sudan; Sir Richard Arden, Senior Education Advisor of DfID, South Sudan. I thank Longhorn and Mountain Top publishers in Kenya for working closely with the Ministry, the Subject Panels, UNICEF and the Curriculum Foundation UK to write the new textbooks. Finally, I thank the former Ministers of Education, Hon. Joseph Ukel Abango and Hon. Dr John Gai Nyuot Yoh, for supporting me, in my previous role as the Undersecretary of the Ministry, to lead the Technical Committee to develop and complete the consultations on the new National Curriculum Framework by 29 November 2013.

The Ministry of General Education and Instruction, Republic of South Sudan, is most grateful to all these key stakeholders for their overwhelming support to the design and development of this historic South Sudan National Curriculum. This historic reform in South Sudan's education system is intended to benefit the people of South Sudan, especially the children and youth and the future generations. It shall enhance the quality of education in the country to promote peace, justice, liberty and prosperity for all. I urge all Teachers to put this textbook to good use.

May God bless South Sudan. May He help our Teachers to inspire, educate and transform the lives of all the children and youth of South Sudan.

Deng Deng Hoc Yai, (Hon.)
Minister of General Education and Instruction, Republic of South Sudan

Contents

Unit 1 Biochemistry of photosynthesis and respiration

Learning outcomes

Knowledge and understanding	Skills	Attitude
• Compare and contrast the biochemistry of photosynthesis and respiration.	• Design and carry out practical investigations on aspects of photosynthesis and respiration • Investigate practically the factors affecting rates of photosynthesis. • Investigate practically leaf structure to understand how gases are exchanged.	• Appreciate the importance of biochemical processes in photosynthesis and respiration in the carbon cycle. • Value the importance of essential elements in supporting life processes.

Introduction

In secondary 2 you learnt about photosynthesis, factors that cause photosynthesis, its importance and adaptation of the leaf to photosynthesis. Are you able to recall this? In this unit we are going to explore more the biochemistry of photosynthesis in plants, and respiration in both plants and animals.

Look at the picture on page 2. What is taking place in the picture? Which similarities can you observe from the picture between the two processes? How are the two processes different from the picture? What is the significance of the above processes in both plants and animals? Can you write the chemical equation of the two processes taking place in the picture?

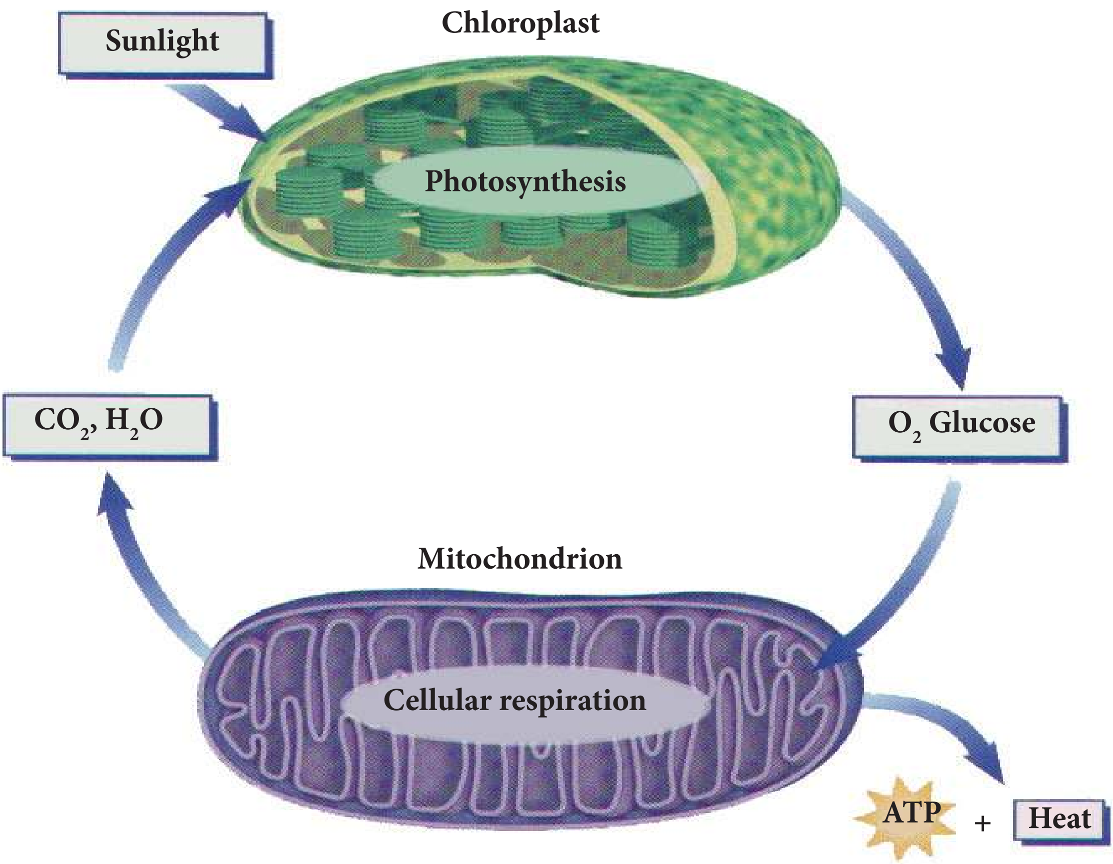


Fig. 1.1: Photorespiration

Plants manufacture their own food through the process of photosynthesis. In this process, carbon (IV) oxide combines with oxygen in the presence of sunlight to form glucose and oxygen as the products.

A commonly used equation for photosynthesis is,

$$\underset{\text{(Carbon IV oxide)}}{6CO_2} + \underset{\text{(Water)}}{6H_2O} \xrightarrow[\text{chlorophyll}]{\text{Light energy}} \underset{\text{(Carbohydrate i.e. glucose)}}{C_6H_{12}0_6} + \underset{\text{Oxygen}}{6O_2}$$

They have chlorophyll which traps light energy from the sun. During this process oxygen is given off as a by-product.

Respiration is the process through which chemical energy present in organic molecules is released through oxidation and it takes place in both plants and animals. In the picture above, glucose is oxidsed in the presence of oxygen to form carbon (IV) oxide, water and energy in form of ATP (Adenosine Triphosphate) as the products. The general equation is as follows;

$$\underset{\text{(Glucose)}}{C_6H_{12}O_6} + \underset{\text{(Oxygen)}}{O_2} \longrightarrow \underset{\text{(Carbon IV oxide)}}{6CO_2} + \underset{\text{(Water)}}{H_2O} + \underset{\text{(Energy)}}{38ATP}$$

Activity 1.1: Testing for the presence of starch in leaves

Work in groups.

Plan and carry out an investigation using the materials shown in the picture below.

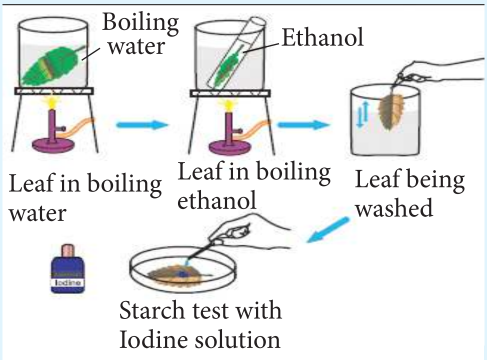


Fig 1.2 Testing for starch in leaves

Study questions

1. Why was the leaf boiled in water and ethanol?
2. Devise another method through the experiment can be carried out.
3. How will we know that the leaf contains starch?

The facts

Change in colour of iodine solution from brown to blue-black shows presence of starch. This means that the part of the leaf tested has starch and therefore photosynthesis must have taken place in that part.

For photosynthesis to take place, certain conditions are necessary. These conditions include the presence of:

- Light energy
- Carbon dioxide
- Water
- Chlorophyll

1.1 Necessity of chlorophyll, light energy and carbon dioxide for photosynthesis

Activity 1.2: To investigate necessity of chlorophyll for photosynthesis

Work in groups

Materials

- Potted plant with variegated leaves
- Ethanol or methylated spirit
- 2 beakers (250 ml)
- Iodine solution
- White tile

Procedure

1. You are provided with the above materials. Design an experiment which shows chlorophyll is necessary for photosynthesis.
2. Write down the steps used to carry out the investigation.

Health Check!

- *Put on eye protection.*
- *Ethanol is highly flammable; therefore remember to put out the flame before putting the boiling tube with the ethanol into the hot water.*

The facts

A variegated leaf is one whose surface shows two colours, for example green on some parts and white on others.

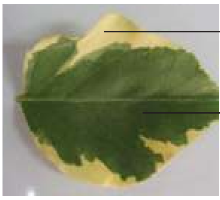


Fig. 1.3: A variegated leaf

The green part of the leaf has cells with chlorophyll. Therefore photosynthesis will take place and form starch. Starch present in this part will turn iodine from brown to a blue-black colour. The yellow part has cells that do not contain chlorophyll. These cells will not carry out photosynthesis; therefore no starch will be formed. The starch test will be negative. The green part of the leaf acts as a control experiment because it has all the conditions required for photosynthesis.

Can you recall all the conditions necessary for photosynthesis as learnt in the previous lesson?

Activity 1.3: To investigate necessity of light in photosynthesis

Work in groups

Materials

- A potted plant
- Black strip of paper
- Cello tape
- 250 ml beakers
- Burner
- Water in a wash bottle
- Match box
- Alcohol
- Iodine solution
- Tripod stand

Procedure

1. You are provided with the above materials. Come up with the steps to follow when determining if light is necessary for photosynthesis. Use the pictures below to guide you.

Fig. 1.4: Experiment showing necessity of light in photosynthesis

2. Come up with the steps to carry out the investigation.

The facts

The leaf turns blue-black except in the covered region when tested with iodine solution. This covered region did not receive light hence photosynthesis did not occur resulting in absence of starch in this region. The uncovered region received sunlight and starch was formed there due to photosynthesis.

As mentioned earlier, photosynthesis involves synthesis of organic food substances by plants. The overall photosynthesis equation is:

$$\text{Water + carbon dioxide} \xrightarrow[\textit{chlorophyll}]{\textit{Light energy}} \text{glucose + oxygen}$$

$$6CO_2(g) + 6H_2O(l) \xrightarrow[\textit{chlorophyll}]{\textit{sunlight}} C_6H_{12}O_6(s) + 6\,O_2(g)$$

End products of photosynthesis

Glucose: This is the main product. It is used in respiration to release energy. Excess glucose is stored as starch or oil.

Oxygen: Some of the oxygen is used during respiration while the rest is released to the atmosphere during gaseous exchange.

Activity 1.4: To show that oxygen is produced during photosynthesis

Work in groups

Materials

- Two large beakers
- Two funnels (glass)
- Two test tubes
- Water with sodium hydrogen carbonate dissolved in it
- Splints
- Match box
- Water weed e.g. *Elodea*, *Spirogyra* or Hydra plant.

Procedure

1. Using the above set of materials, design an experiment to show that oxygen is always produced during photosynthesis.
2. Draw a well labelled diagram to illustrate this experiment.

Note:

Set-up A placed in a dark cupboard

Set-up B placed in bright sunshine.

1. Observe the set-up in the dark cupboard.
   - What did you notice?
2. Observe the set-up in the bright sunshine.
   - What do you notice?
3. Test any gas produced using a glowing splint.

Study questions

(a) What is the role of the sodium hydrogen carbonate (sodium bicarbonate) dissolved in the water?

(b) What happens to the glowing splint when it is exposed to the gas in the test tubes?

(c) What is your conclusion from the observation?

(d) What was the role of the set-up that was placed in the dark cupboard?

The facts

After sometime, bubbles will be seen coming out from the water weed plants used.

In presence of sunlight, photosynthesis takes place producing oxygen as a by-product. Oxygen relights a glowing splint. In darkness, no photosynthesis takes place. The set-up in the dark cupboard therefore does not produce any oxygen.

Check your progress 1.1

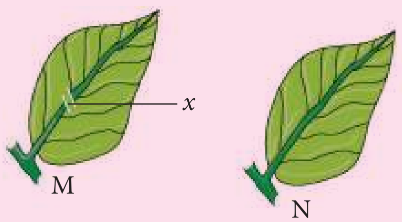
1. Below is an incomplete symbolic equation of photosynthesis.

$$\text{Water} + \begin{matrix}\text{carbon}\\ \text{dioxide}\end{matrix} \xrightarrow[Y]{\textit{sunlight}} X + \text{oxygen}$$

   (a) What does Y represent?

   (b) What is product X?

2. The figure below shows an experiment that was carried out on two green leaves. The mid-rib of leaf **M** was severed at point *x* while still attached to the tree in an evening of a sunny day. The mid-rib of leaf **N** was left intact. The two leaves were detached from the plant and tested for starch.



   (a) Account for the distribution of starch in part of leaf **M**.

   (b) There was complete absence of starch in leaf **N**. Account for this.

1.2 Limiting factors of photosynthesis

A **limiting factor** is a variable which limits the rate of photosynthesis.

The process of photosynthesis does not always take place efficiently. Sometimes there are some factors that hinder its progress. Photosynthesis may be limited by a shortage in supply of one or more raw materials or other factors necessary for photosynthesis.

Discussion corner

1. Discuss with your classmates the effects of the following on the process of photosynthesis under the following conditions:
   (i) Very low temperatures.
   (ii) Cloudy conditions.
   (iii) Very high light intensity.
   (iv) Low carbon dioxide.
2. What does this tell you about the process of photosynthesis.

The facts

Some of these factors are given below.

a) Light intensity

Investigating the rate of photosynthesis

This is an example of a common experiment used to investigate light intensity and the rate of photosynthesis. This should help you understand how to work scientifically.

Activity 1.5: What is the effect of light on the rate of photosynthesis?

Work in groups

Materials

1. Elodea plant
2. Test tube
3. Beaker
4. Fresh water
5. Ruler
6. Stop watch
7. Lamp or candle

Procedure

1. Set up the diagram below using the materials provided above.

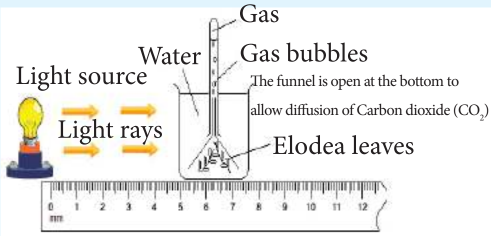


Fig 1.5 How light intensity affects rate of photosynthesis

2. Using a ruler, vary the length of the source of light as you record the number of bubbles produced in a minute as shown in the diagram above.
3. Record your results in the table below.

Distance between the pond weed and light source in (centimetre)	Number of bubbles given off in 1 minute

4. Plot a graph of number of bubbles produced per minute against light intensity.
5. Write a summary note of the experiment above using the graph plotted.
6. Compare your results with the other groups and discuss the results.

Light is a necessity for photosynthesis to occur. In darkness, plants cannot carry out photosynthesis at all. In low light intensity, the rate of photosynthesis is low. But as light intensity increases, the rate of photosynthesis also increases. There reaches a point where the plant cannot photosynthesise any faster even with further increase in light intensity. At this point, any other factor affecting the rate of photosynthesis hinders the rate of photosynthesis.

Activity 1.6: To determine the effect of carbon dioxide concentration on the rate of photosynthesis

Work in groups.

Design an experiment to determine the effect of carbon dioxide concentration on the rate of photosynthesis.

Problem statement

What is the effect of carbon dioxide concentration on the rate of photosynthesis?

Hypothesis

When the concentration of carbon dioxide increases, the rate of photosynthesis also increases until the rate becomes constant.

Variables

Manipulated:

- Concentration of carbon dioxide responding.
- The rate of photosynthesis.
- The number of bubble released per minute constant.
- Light intensity

- Temperature/Size of plant

Apparatus and materials

Elodea/Hydrilla, different concentration of sodium bicarbonate, distilled water.

b) Carbon dioxide concentration

The amount of carbon dioxide in the atmosphere is quite low (0.03%). Therefore it can also be a limiting factor to photosynthesis. Increase in carbon dioxide increases the rate of photosynthesis. But this continues only to a certain point where rate of photosynthesis does not increase further with more carbon dioxide since other factors affecting photosynthesis become limiting.

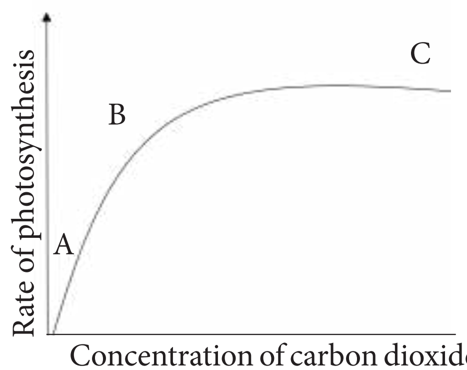


Fig. 1.6: Graph of effect of carbon dioxide concentration on the rate of photosynthesis

AB: Increase in concentration of carbon dioxide causes a rise in rate of photosynthesis.

BC: Limiting factors set in and a further rise in carbon dioxide concentration does not cause a corresponding increase in rate of photosynthesis.

c) Temperature

Photosynthesis is an enzyme- catalysed reaction and is therefore affected by temperature. If temperatures are low, plants photosynthesise very slowly; but as temperature increases, the rate of photosynthesis also increases. Rate of photosynthesis is highest at optimum temperature. Further increase in temperature above optimum results to a decrease in rate of photosynthesis since enzymes are denatured.

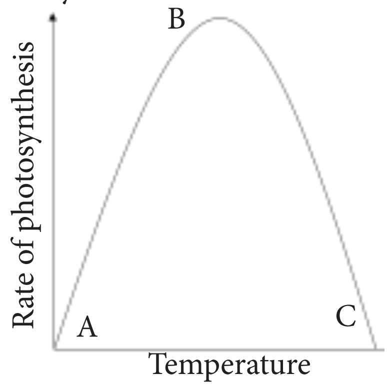


Fig. 1.7: Effect of temperature on the rate of photosynthesis

AB – Increase in temperature causes a corresponding increase in the rate of photosynthesis. The rate of photosynthesis is highest at B.

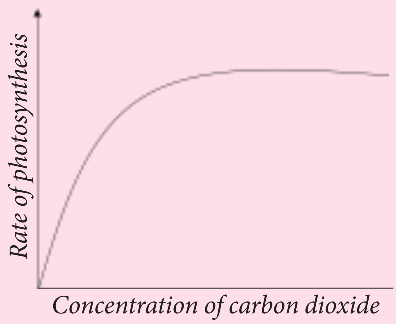
BC – Any further increase in temperature denatures the enzymes. Therefore the rate of photosynthesis declines.

d) Water

Only about 1% of the water taken in by plants is used for photosynthesis. Water shortage only indirectly affects the rate of photosynthesis, for instance, when water is in short supply, the stomata close. This lowers the exchange of gases between the leaf and the atmosphere. As a result, less carbon dioxide diffuses via the stomata into the leaf. This reduces the rate of photosynthesis.

Check your progress 1.2

1. Which of the following is not a limiting factor in photosynthesis?
   A. Amount of oxygen
   B. Concentration of chlorophyll
   C. Light intensity
   D. Temperature
   E. Carbon dioxide concentration
2. The graph below shows the effect of increasing carbon dioxide on the rate of photosynthesis.



   Explain why the rate of photosynthesis does not continue to increase with increase in carbon dioxide concentration.
3. Temperature is a factor that limits the rate of photosynthesis. Explain why the rate of photosynthesis starts to decrease as temperature increases beyond 40°C and eventually stops beyond 60°C.
4. The atmospheric air contains 0.03% carbon dioxide. What will happen to the rate of photosynthesis if carbon dioxide level rises to 4%?

1.3 Internal structure of the leaf and its adaptations to photosynthesis

Activity 1.7:

1. Using textbooks and the internet, research on the adaptation of the leaf for photosynthesis.

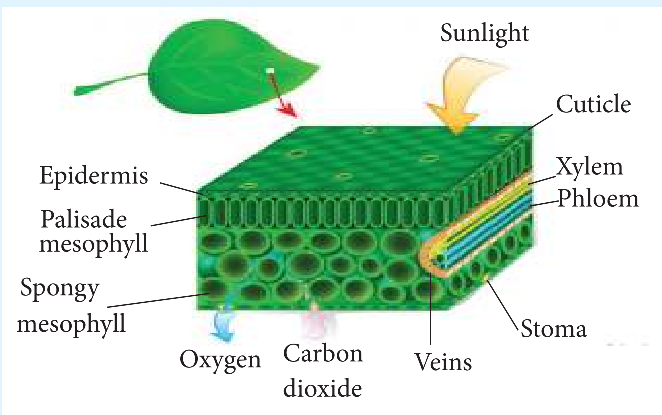


Fig 1.8 External and internal structure of the leaf

2. Write down short notes regarding your findings.
3. Discuss your findings with the rest of your class members.

The leaf is the main organ for photosynthesis. However, other green parts of the plant carry out photosynthesis as well. The structure of the leaf is well suited for photosynthesis. Look at the diagram on page 9. It shows the internal parts of the leaf.

The leaf has a cuticle which covers both upper and lower surfaces of the leaf. Immediately after the cuticle is the upper and lower epidermis respectively. The palisade mesophyll which contains palisade cells that carry out photosynthesis is located below the upper epidermis. Its is followed by the spongy mesophyll which has cells with large air spaces between them. On the lower epidermis are tiny openings called stomata. They are surrounded by special cells known as guard cells.

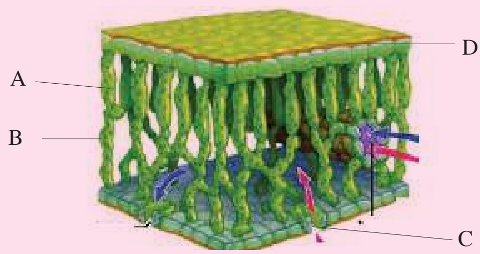
The facts

The following are some of the adaptations of the leaf to photosynthesis:

- The leaf blade is broad and flat to provide a large surface area for absorption of sunlight and carbon dioxide.
- Most leaves are thin. This reduces the distance across which carbon dioxide has to diffuse from the stomata to reach the photosynthesising cells.
- Leaves have vascular bundles that contain structures (xylem and phloem) which supply the cells with water and mineral salts. The vascular bundles also transport manufactured food to the other parts of the plant.
- The leaf cuticle and epidermis are transparent and thin to allow easy penetration of light.
- Presence of stomata on the leaves allows easy diffusion of carbon dioxide.
- The leaves are well arranged to avoid overlapping and overshadowing. This ensures maximum exposure to light.
- The spongy mesophyll layer has cells that are irregular in shape and are loosely arranged hence have large air spaces between them. This allows gases to circulate freely thereby enhancing gaseous exchange between the cells and the air surrounding them.
- Palisade cells are closely packed. Further, they are elongated and lie at right angles to each other. They also contain many chloroplasts hence absorb maximum sunlight required for photosynthesis.

Check your progress 1.3

1. Use the diagram of the cross-section through the leaf to answer the questions that follow.



(a) Indicate on the diagram the following: guard cells, spongy mesophyll layer, palisade layer and vascular bundles.

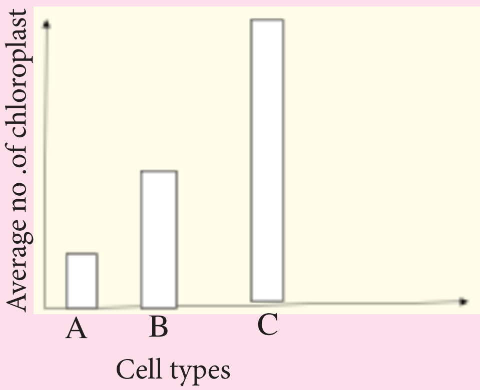
(b) Which cell type absorbs most carbon dioxide during the day?

(c) State the role of the part labelled D in photosynthesis.

(d) Describe ways in which cell type B are suited for photosynthesis.

(e) Of what importance is the shape of cell type C in photosynthesis?

2. The bar chart below shows the average number of chloroplasts in the different types of cells in a leaf.



Identify the cell types A, B and C.

3. Differentiate between the following:
   (a) Epidermal cell and guard cell.
   (b) Palisade layer and spongy layer.
4. Explain the role of vascular bundles in photosynthesis.

1.4 Importance of photosynthesis

Activity 1.8

Work in pairs

1. Discuss with a friend the following questions:
   (a) How would life be on earth without photosynthesis?
   (b) What do you think are the importance of photosynthesis?
2. Share your findings with the class.

Class Activity: Debate

Organise a class debate with a motion: Deforestation is the main cause of global warming.

Check your progress 1.4

1. Describe the role of plants in an ecosystem.
2. Suggest conservation methods you can initiate in your village to prevent environmental degradation.

1.5 The process of photosynthesis

Activity 1.9

Work in groups.

Study the diagram below carefully.

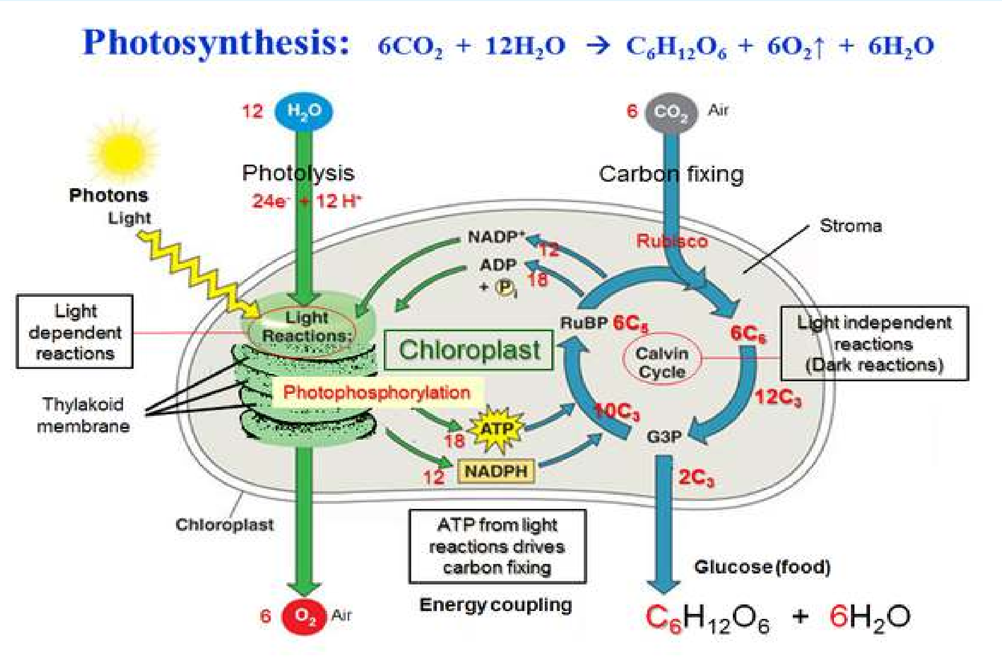


Fig 1.9: Stages of photosynthesis

Study questions

a) Discuss from the diagram the photolysis process using an equation.
b) Where does light stage and dark stage take place in the chloroplast?
c) Compare and contrast the two stages of photosynthesis.
d) Discuss the Calvin cycle using an equation.

The facts

Photosynthesis occurs through a series of chemical reactions. These reactions can be divided into two main stages.

The first stage requires light energy and is called **the light stage**. The second stage does not require light energy and is called the **dark stage** or the **light independent stage**.

The light stage

It takes place in the **grana** of the chloroplast. During this stage, chlorophyll absorbs light energy. This energy is used in two ways.

(i) Some is used to split up water molecules into **hydrogen ions** and **oxygen**. This is known as photolysis of water. The word *photo* means light and *lysis* means splitting. The hydrogen ions produced are used in the dark stage. Some of the oxygen formed is released from the leaf through the stomates. The rest is used up in the plant cells for respiration.

$$\underset{\text{water}}{2H_2O} \longrightarrow \underset{\text{hydrogen ions}}{4H^+} + \underset{\text{oxygen}}{O_2}$$

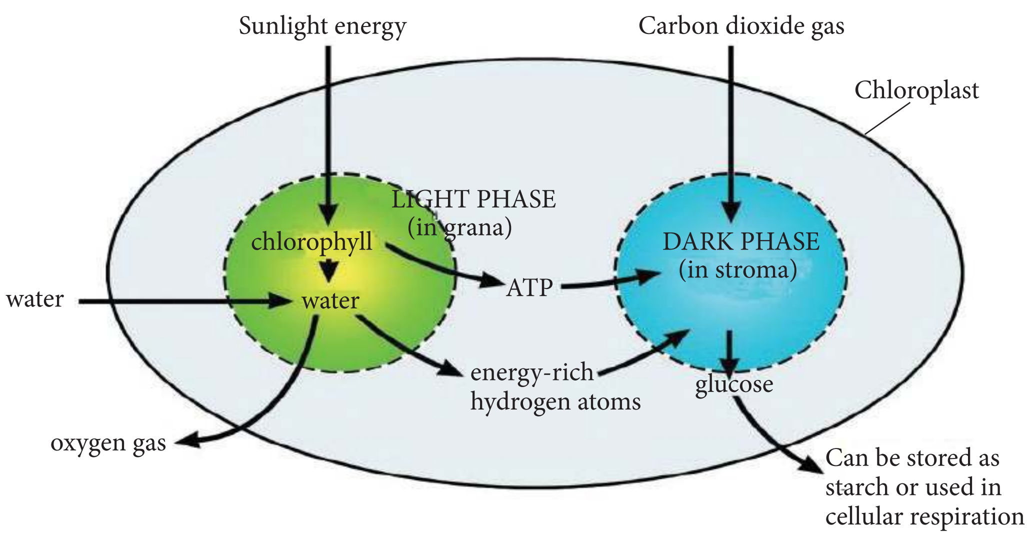
(ii) Some of the absorbed sunlight energy is converted to ATP. The ATP is used in the dark stage.

ATP (Adenosine triphosphate) is a high energy compound consisting of an adenosine molecule bonded to three phosphate groups. It is present in all living tissues. The breakage of one phosphate (energy-rich bond) linkage to form ADP (adenosine diphosphate) provides energy for physiological processes such as muscular contractions.

The dark stage

The dark stage takes place in the **stroma** at the same time that the light stage is taking place in the **grana**. Carbon dioxide diffuses into the stroma from the cell cytoplasm. The hydrogen from the light stage combines with carbon dioxide to form glucose. This process uses the energy stored during the light stage and also requires enzymes. The manufacture of a carbohydrate (glucose) from carbon dioxide is called **carbon dioxide fixation**.

$$\underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{hydrogen ions}}{4H^+} \longrightarrow \underset{\text{simple sugar (glucose)}}{(CHO)_2} + \underset{\text{water}}{H_2O}$$



1.10 : The light phase and the dark phase of photosynthesis

1.6 Chemical compounds which constitute living organisms

All living things are made up of chemical compounds. Some of these are described as **organic compounds**. These are complex compounds which contain mainly **carbon**, **hydrogen** and **oxygen**. A few organic compounds also contain phosphorus, sulphur and nitrogen. Examples of organic compounds are **carbohydrates**, **lipids**, **proteins**, and **vitamins**.

Other compounds found in living organisms are described as **inorganic**. These are simple in structure. Examples are **mineral salts**, **water**, **acids** and **bases**.

Both organic and inorganic compounds are important in the structure and function of cells.

Chemical composition and functions of carbohydrates, proteins and lipids

Activity 1.10

Work as a group

Materials

Reference materials such as textbooks.

Procedure

1. Carry out a research on different types of organic compounds and how carbon and hydrogen atoms link to create hydrocarbons using the textbooks provided.
2. Write down short notes in your exercise books.
3. Compare your results with those of other groups.

Study questions

1. Identify the different types of organic molecules.
2. How do the atoms such as carbon, oxygen, nitrogen and hydrogen form different organic molecules?

(a) Carbohydrates

These are chemical compounds made up of the elements **carbon**, **hydrogen** and **oxygen**. Their general formula is $\mathbf{(CH_2O)_n}$. Common examples of carbohydrates are **sugars** and **starch**. Carbohydrates are classified into three main groups:

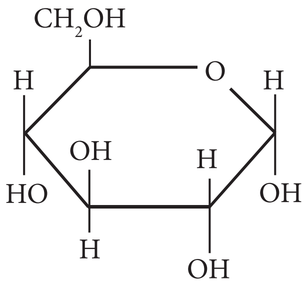
- Monosaccharides
- Disaccharides
- Polysaccharides

(i) Monosaccharides

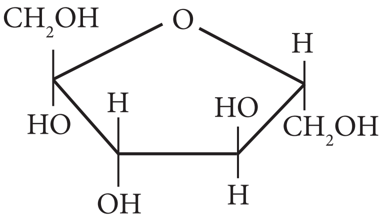
A monosaccharide is a single sugar unit. The general formula of a monosaccharide is $(CH_2O)_n$ where n can be 3, 5 or 6. Some examples of monosaccharides are glucose, fructose and galactose.

Table 1.1: Examples of monosaccharides and their sources

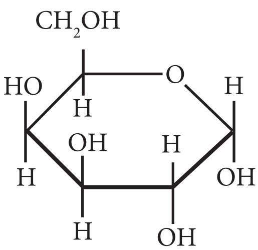
Monosaccharides	Where found
• Glucose	Cell cytoplasm, blood of vertebrates
• Fructose	ripe fruits
• Galactose	milk



1.9: Structure of glucose



1.10 : Structure of fructose



1.11: Structure of galactose

ii) *Disaccharides*

A disaccharide is a double sugar formed when two monosaccharide molecules combine. The chemical process that forms a disaccharide from the two monosaccharides is called a **condensation reaction**. In this process, a water molecule is formed and released. Disaccharides are soluble in water and taste sweet.

Example

monosaccharide + monosaccharide $\xrightarrow{\textbf{\textit{condensation}}}$ **disaccharide + water**

$$C_6H_{12}O_6 + C_6H_{12}O_6 \underset{\text{Hydrolysis}}{\overset{\text{Condensation}}{\rightleftharpoons}} C_{12}H_{22}O_{11} + H_2O$$

(dissacharides)

Condensation is a reversible reaction. The disaccharide can be split by the addition of water to form two monosaccharides. This chemical reaction is called **hydrolysis**.

Example

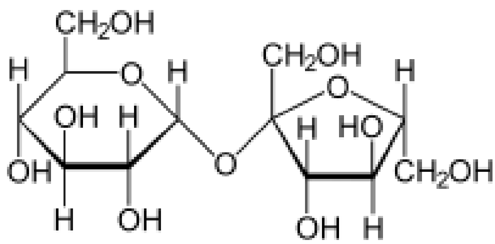
disaccharide + water $\xrightarrow{\textbf{\textit{hydrolysis}}}$ **monosaccharide + monosaccharide**

In the cells, enzymes speed up the process. Outside the cell, hydrolysis is achieved by boiling the disaccharide with hydrochloric acid. Some common examples of disaccharides are **maltose**, **lactose** and **sucrose**. The following are word equations to show how they are formed.

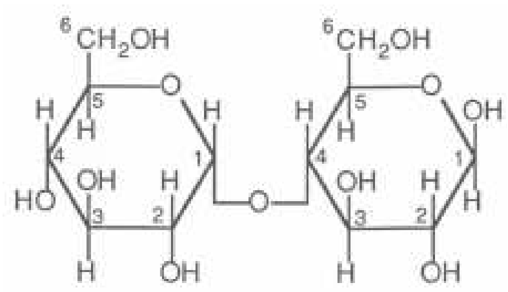
1. glucose + glucose → maltose + water
2. glucose + galactose → lactose + water
3. glucose + fructose → sucrose + water

Table 1.2: Examples of disaccharides and their sources

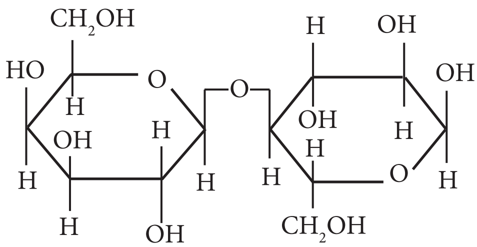
Disaccharides	Where found
Sucrose (cane sugar)	Present in green plants. It is commercially extracted from sugarcane and sugar beet.
Maltose (malt sugar)	In germinating barley
Lactose (milk sugar)	In milk of all mammals



1.12: Structure of sucrose



1.13: Structure of maltose



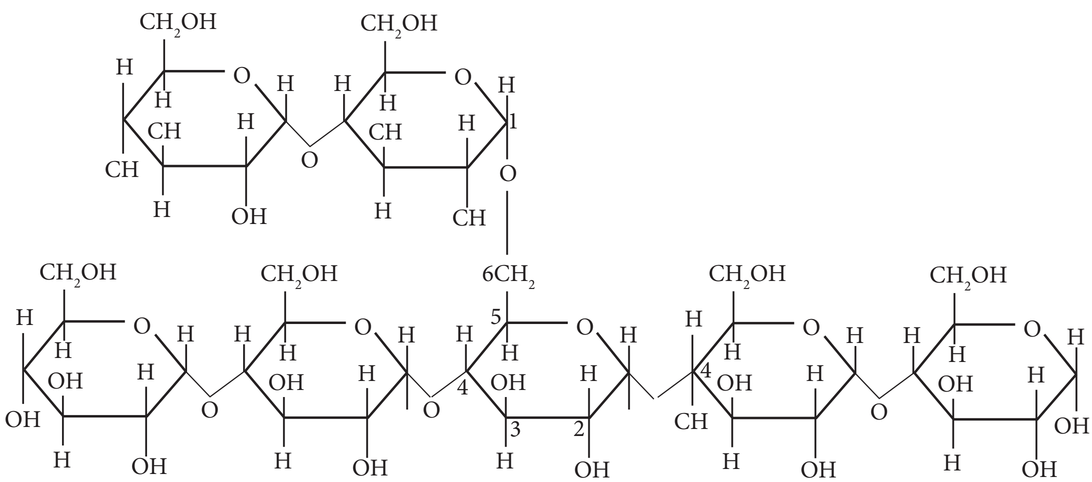
1.14: Structure of lactose

iii) Polysaccharides

A polysaccharide is a large complex carbohydrate molecule formed when many monosaccharide molecules link up in condensation reactions. The hydrolysis of a polysaccharide therefore gives rise to many monosaccharide units. Some common examples of polysaccharides are **starch**, **cellulose** and **glycogen**.

(a) Starch

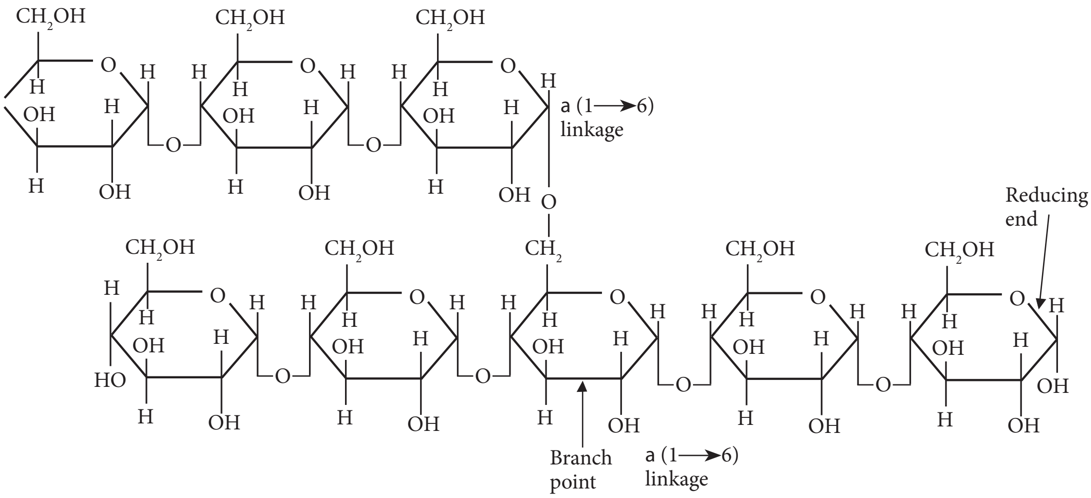
Starch is the storage form of glucose in plants. Each starch molecule has about 300 - 1000 glucose units. Most starch in plants can be found in seeds and storage organs like potato tubers. It gives a blue-black colour with iodine in potassium iodide solutions. This is the laboratory test for starch.



1.15: Structure of starch

(b) Glycogen

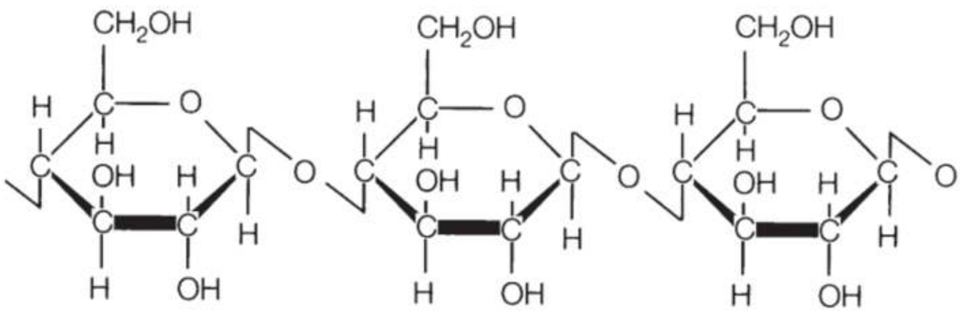
Glycogen is the main storage form of glucose in animals. It is made up of about 30,000 glucose molecules. Large amounts of glycogen are found in the liver. It is also found in muscles attached to the skeleton. Fungi also store carbohydrate in form of glycogen.



1.16: Structure of glycogen

(c) Cellulose

A molecule of cellulose may have as many as 14,000 glucose units. It is the most abundant of all molecules found in plants. It is found as the major part of the structure of cell walls in plants. Wood is largely made up of cellulose and other substances. Cotton is almost purely made of cellulose. Cellulose is fibrous, tough and insoluble in water. Because of its fibrous nature, it is used by man to make cotton goods. It is also used to make paper.



1.17: Structure of cellulose

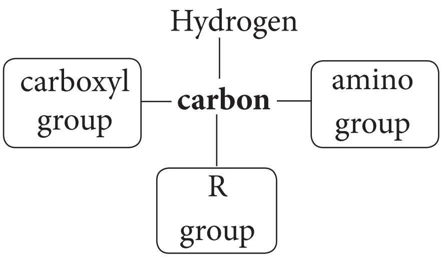
(b) Proteins

Proteins are complex compounds. They too are made up of the elements carbon, hydrogen and oxygen. In addition, they have nitrogen. Some proteins may also contain sulphur or phosphorus. These elements make up units called **amino acids**.

The general structure of an amino acid

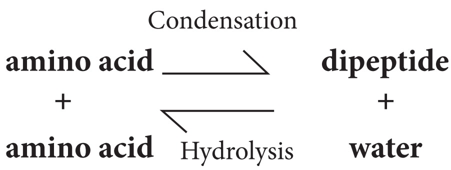
Amino acids are the building units of proteins. There are about twenty different types of amino acids which occur naturally in plants and animals. These amino acids combine differently in a chain to form different types of proteins. There exists a large variety of proteins.

An *amino acid* molecule is made up of three groups of atoms linked to a central carbon. These groups are the same in all amino acids except for the functional R group.



Peptides

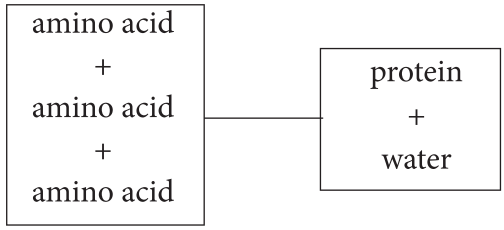
Peptides are molecules formed when a few amino acids combine.When two amino acid molecules combine, they form a **dipeptide**. This process is a condensation reaction which involves the removal of a water molecule.



The two amino acids are joined by a force called a **peptide bond**. Condensation is a reversible reaction. This means that it is possible to get back the substances which we began the reaction with. The reverse process is called *hydrolysis*.

If three amino acids combine by condensation, the compound formed is called a **tripeptide**.

When a large number of amino acids combine by condensation, then the new molecule formed is very large. It is called a **polypeptide**. The word **poly** means many. Polypeptide molecules are also called **protein molecules**.



There are many possible combinations of amino acids in the formation of proteins. This results in a greater variety of proteins compared to carbohydrates. This is because the types of building units of carbohydrates (monosaccharides), are fewer than those for building protein (amino acids). Complex polypeptides are long chains of up to several thousand amino acids.

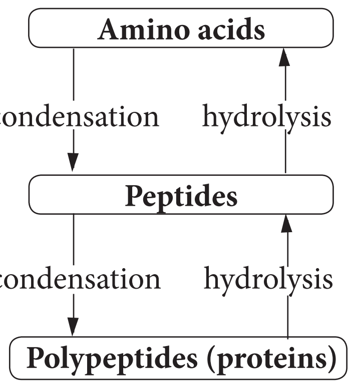


Fig. 1.18: Summary diagram showing formation and breakdown of proteins

Properties of proteins

- They form large complex structures which are insoluble in water.
- High temperatures and extreme pH permanently alter their chemical structure and make them functionless (denatured).

(c) Lipids

Lipids are fats and oils. The elements found in lipids are the same as those in carbohydrates, namely carbon, hydrogen and oxygen. However, lipids have much fewer oxygen atoms than hydrogen atoms compared with carbohydrates. For example, in glucose which is a carbohydrate, there are two hydrogen atoms for every oxygen atom. In a lipid, there are **twenty two** hydrogen atoms for every oxygen atom. Fats are lipids commonly found in **animal** tissue. An exception is the whale which has oil. Oils are lipids commonly found in **plants**.

The building units in a lipid molecule are **fatty acids** and **glycerol**. One glycerol molecule combines with three fatty acid molecules in a condensation reaction to form a lipid known as a **triglyceride**. Three water molecules are given out. This reaction can be reversed by hydrolysis where the triglyceride (lipid) is split to glycerol and three fatty acid molecules.

There are different types of fatty acid molecules but only one type of glycerol. The type of lipid formed depends on the types of fatty acid molecules that it contains.

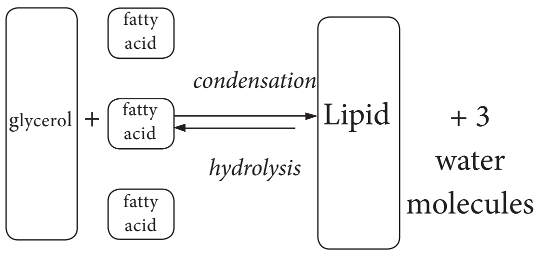
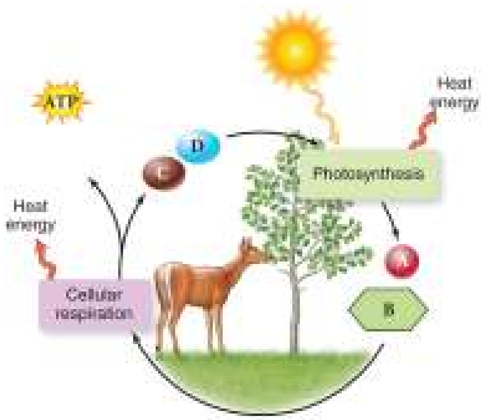


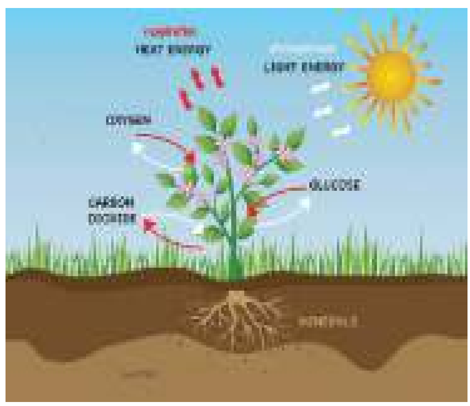
Fig. 1.19: Summary of the formation and breakdown of a lipid

1.7 Respiration

In secondary 2, we learnt about different types of respiration and how they take place in living organisms. In this class, we shall explore more on the biochemistry of respiration in relation to energy production and the processes involved.



A



B

Look at the illustrations above. What makes plants grow? How do the plants make their food for growth? How does respiration take place in both plants and animals? What are the end products of respiration? What do letters A, B, C and D represent?

The facts

Respiration can be defined as a biochemical process by which foods are oxidised to liberate energy. Overall respiration involves two processes:

- It is a stepwise oxidation of complex organic molecules and release of energy as ATP for various cellular metabolic activities.
- The plants obtain oxygen from their environment and return carbon dioxide and water vapour into it. This mere exchange of gases is known as external respiration or breathing in the case of animals.

It is a physical process. The biochemical process, which occurs within cells and oxidises food to obtain energy, is known as **cellular respiration**.

Types of respiration

Activity 1.11: Discussion

Work in groups

1. Talk to your friend about the following questions:
   i. Why do you have to breathe in quickly during a physical exercise?
   ii. What causes pain in the legs after an exercise?
   iii. What makes milk go bad when not stored properly?
   iv. Differentiate between aerobic and anaerobic respiration.
2. Share your findings with the rest of the class.

The facts

There are two kinds of respiration depending on whether oxygen is required or not. Respiration that requires oxygen in order to take place is known as **aerobic respiration. Anaerobic** respiration takes place in the absence of oxygen.

The first steps of both aerobic and anaerobic respiration are the same. They involve splitting glucose into **pyruvic acid.** This process is known as **glycolysis,** which means sugar-splitting (usually one molecule of glucose is split into two molecules of pyruvic acid). It takes place in the cytoplasm and does not require the presence of oxygen. Only 2 ATPs of energy are produced during this process.

Aerobic respiration

Aerobic respiration occurs when glucose is broken down in the presence of oxygen. A lot of energy (many ATP molecules) is produced.

It occurs in all higher forms (organisms). In this type, oxygen is necessary.

Aerobic respiration is summarised in the equation below.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + 2880 \text{ K joule}$$

There are three stages in aerobic respiration, namely:

a) glycolysis
(b) the Krebs cycle
c) oxidative phosphorylation

Activity 1.12

Study the following diagram carefully and answer the following questions.

a) What do you understand by the term glycolysis?
b) Where does glycolysis take place in animals?
c) What are the end products of glycolysis?

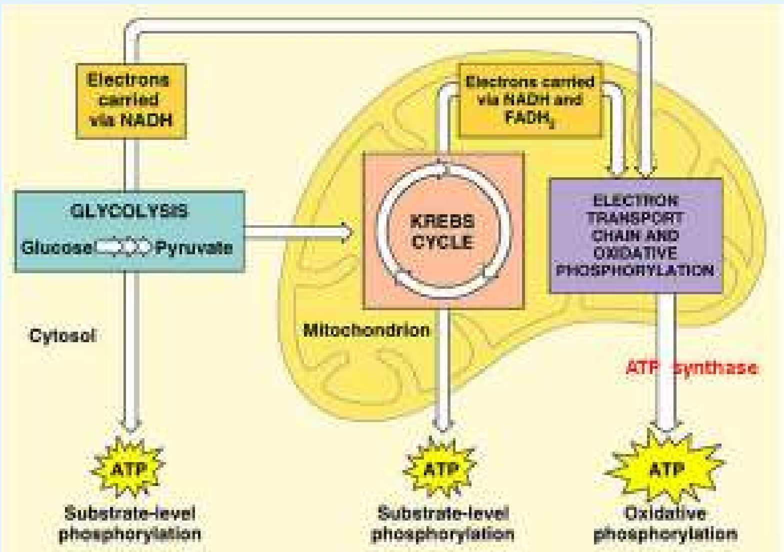


Fig. 1.20: Stages of aerobic respiration

The facts

a) **Glycolysis:** This occurs in the cytoplasm of the cell. Glucose is broken down into pyruvic acid and energy-rich hydrogens are given off.

The hydrogens move into the mitochondria to be used in oxidative phosphorylation.

Two ATP molecules are produced during glycolysis.

b) **The Krebs cycle** breaks down the pyruvic acid completely into energy-rich hydrogens and carbon dioxide. The hydrogens will be used in oxidative phosphorylation and the carbon dioxide will be breathed out.

- The Krebs cycle is the second stage of cellular respiration.
- During the Krebs cycle, energy stored in pyruvate is transferred to NADH and $FADH_2$, and some ATP is produced.

Activity 1.13:

Work in groups

Study the following diagram.

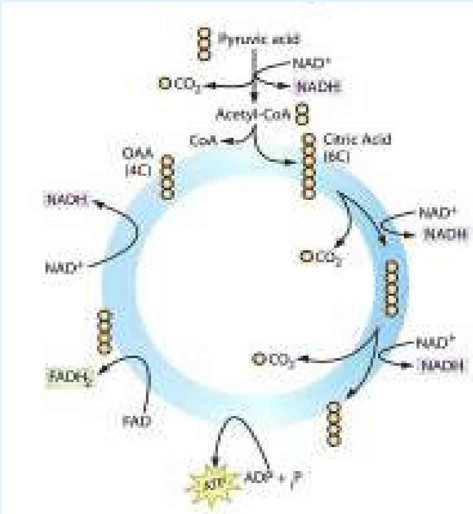


Fig. 1.21: The Krebs cycle

Study questions

a) What is the Krebs cycle?

b) What are the products of the Krebs cycle?

The facts

Before the Krebs cycle begins, pyruvic acid, which has three carbon atoms, is split and combined with an enzyme known as CoA, which stands for coenzyme A. The product of this reaction is a two-carbon molecule called acetyl-CoA. The third carbon from pyruvic acid combines with oxygen to form carbon dioxide, which is released as a waste product. High-energy electrons are also released and captured in NADH.

Steps of the Krebs cycle

The Krebs cycle itself actually begins when acetyl-CoA combines with a four-carbon molecule called OAA (oxaloacetate). This produces citric acid, which has six carbon atoms. This is why the Krebs cycle is also called the **citric acid cycle**.

After citric acid forms, it goes through a series of reactions that release energy. The energy is captured in molecules of NADH, ATP and $FADH_2$, another energy-carrying compound. Carbon dioxide is also released as a waste product of these reactions.

The final step of the Krebs cycle regenerates oxaloacetate (OAA), the molecule that began the Krebs cycle. This molecule is needed for the next turn through the cycle. Two turns are needed because glycolysis produces two pyruvic acid molecules when it splits glucose.

c) Oxidative phosphorylation

Oxidative phosphorylation (or OXPHOS in short) is the metabolic pathway in which cells use enzymes to oxidise nutrients, thereby releasing energy which is used to produce adenosine triphosphate (ATP).

- In most eukaryotes, this takes place inside the mitochondria.
- It takes the energy from the energy-rich hydrogens to make ATP.

- The energy depleted hydrogens combine with oxygen to make water. This is either breathed out as water vapour or excreted via the kidneys.

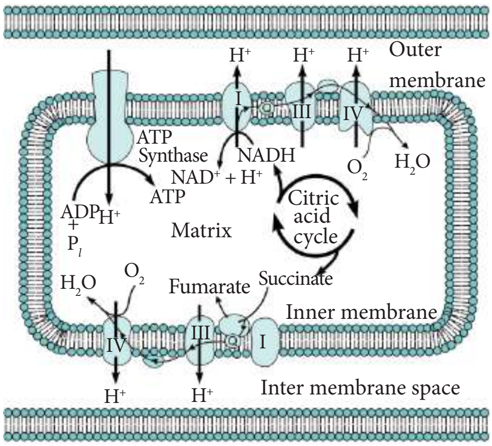


Fig. 1.22: Oxydative phosphorylation

Anaerobic respiration

Anaerobic respiration occurs when glucose is broken down and there is no oxygen present. Very little energy is produced.

There are two types of anaerobic respiration:

a) Alcoholic fermentation, which converts glucose into ethanol through a process known as **glycolysis**.

b) Lactic acid fermentation which splits glucose into two molecules of lactic acid to produce ATP energy.

Anaerobic respiration only occurs in humans when the oxygen supplied to muscles is used up and the muscles still require energy. This produces lactic acid and leads to the muscle fatigue during and stiffness after exercising.

$C_6H_{12}O_6 \longrightarrow C_2H_5OH$(ethyl alcohol) + CO_2 + 210 K joule (example yeast)

$C_6H_{12}O_6 \longrightarrow C_3H_2O$-3 (lactic acid)+ energy (example intestinal worm)

Table 1.3: Differences between aerobic and anaerobic respiration

Aerobic respiration	Anaerobic respiration
Requires oxygen to take place.	Does not need oxygen in order to take place.
There is complete breakdown of glucose molecule.	There is incomplete breakdown of glucose; leading to the formation of intermediate compounds.
Large amount of energy released from each molecule of glucose.	Much less energy released from each molecule of glucose.
The by-products formed are carbon dioxide and water.	The by-products formed are carbon dioxide and ethanol in plants and lactic acid in animals.

Aerobic respiration	Anaerobic respiration
Occurs in the cytoplasm and in the mitochondrion.	Occurs only in the cell cytoplasm.

Check your progress 1.5

1. How do plant and other organisms obtain energy for various activities such as growth?
2. Name the energy rich molecule formed during respiration from food.

Table 1.4: The difference between respiration in plants and animals

Respiration in plants	Respiration in animals
All the parts of a plant (like root, stem and leaves) perform respiration individually.	An animal performs respiration as a single unit.
During respiration in plants, there is a little transport of respiratory gases from one part of the plant to the other.	Respiratory gases are usually transported over long distance inside an animal during respiration.
The respiration in plants occurs at a slow rate.	The respiration in animals occurs at a much faster rate.

Respiration in plants

- Like animals, plants also need energy and plants get this energy by the process of respiration.
- Plants also use oxygen for respiration and release carbon dioxide.

Plants get oxygen by diffusion:

- Plants have a branching shape, so they have quite a large surface area in comparison to their volume. Therefore, diffusion alone can supply all the cells of the plants with as much oxygen as they need for respiration.
- Diffusion occurs in the rots, stems and leaves of plants.

Respiration in roots

- Oxygen in soil diffuses through root hair and reaches all internal cells of the root for respiration.
- Carbon dioxide produced by root cells diffuses in the opposite direction.
- In water-logged conditions, soil air becomes deficient.
- In the absence of oxygen, the metabolic activity of the root declines and the plant may wither.

Respiration in stems

- The stems of herbaceous plants have stomata. The oxygen from air diffuses into the stem of a herbaceous plant through stomata and reaches all the cells for respiration.
- The carbon dioxide gas produced during respiration diffuses out into the air through the same stomata.

- In woody stems, the bark has lenticels for gaseous exchange.

Respiration in leaves

- The leaves of a plant have tiny pores called stomata. The exchange of respiratory gases in the leaves takes place by the process of diffusion through the stomata.

Net gaseous exchange in the leaves of the plant

- During day time, when photosynthesis occurs, oxygen is produced. The leaves use some of this oxygen for respiration and the rest of the oxygen diffuses out into air.
- Again, during the day time, the carbon dioxide produced by respiration is all used up during photosynthesis by the leaves. Even more carbon dioxide is taken in from air.
- Thus, **net gas exchange in leaves during day time is: O_2 diffuses out; CO_2 diffuses in**.
- At night, little photosynthesis occurs and hence no oxygen is produced, oxygen from air diffuses into leaves to carry out respiration. The carbon dioxide produced by respiration diffuses out into air.
- Thus, **net gas exchange in leaves at night is: O_2 diffuses in; CO_2 diffuses out**.

Importance of respiration in the carbon cycle

Photosynthesis and cellular respiration are connected through an important relationship. This relationship enables life to survive, as we know it. The **products** of one process are the reactants of the other. Notice that the equation for **cellular respiration** is the direct opposite of **photosynthesis**:

- Cellular respiration: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$
- Photosynthesis: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

Photosynthesis makes the glucose that is used in cellular respiration to make ATP. The glucose is then turned back into carbon dioxide, which is used in photosynthesis. While water is broken down to form oxygen during photosynthesis, in cellular respiration oxygen is combined with hydrogen to form water. While photosynthesis requires carbon dioxide and releases oxygen, cellular respiration requires oxygen and releases carbon dioxide. It is the released oxygen that is used by us and most other organisms for cellular respiration. We breathe in that oxygen, which is carried through our blood to all our cells. In our cells, oxygen allows cellular respiration to proceed. Cellular respiration works best in the presence of oxygen. Without oxygen, much less ATP would be produced.

Cellular respiration and photosynthesis are important parts of the carbon cycle. The **carbon cycle** is the pathway through which carbon is recycled in the biosphere. While cellular respiration releases carbon dioxide into the environment, photosynthesis pulls carbon dioxide out of the atmosphere. The exchange of carbon dioxide and oxygen during photosynthesis and cellular respiration in the atmosphere helps to keep atmospheric oxygen and carbon dioxide at stable levels.

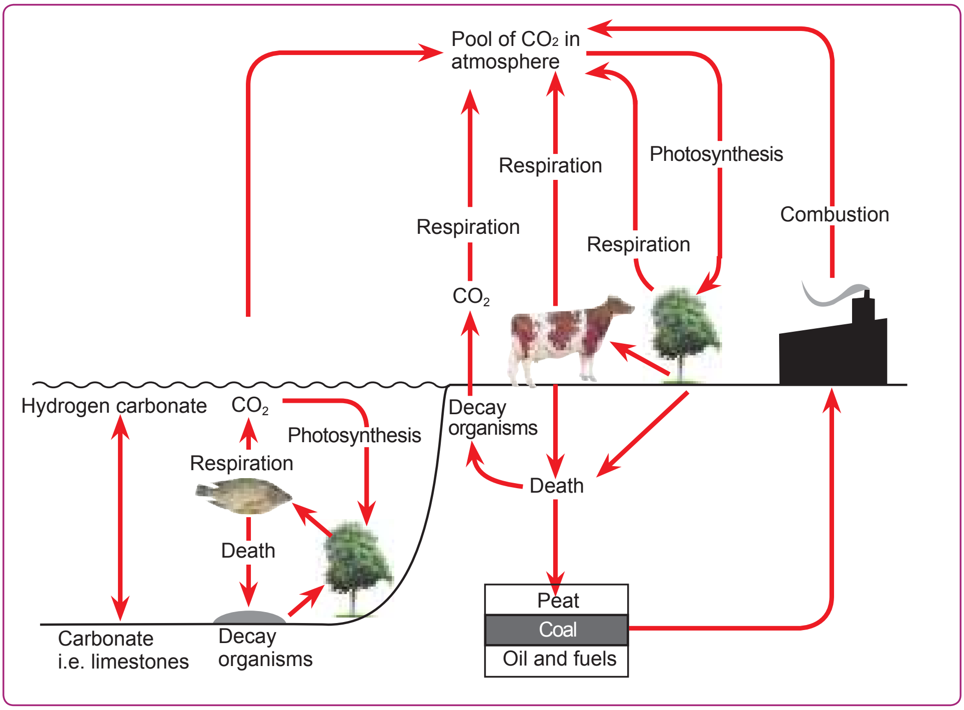


Fig. 1.23: Carbon cycle

1.8 Respiratory system in animals

- A living organism requires oxygen for various metabolic processes in the cells. Most water inhabiting animals get oxygen from the water while land-dwelling animals get it from the air.
- After using the oxygen for various metabolic processes, CO_2 released has to diffuse out of the cell or the body.
- The process of acquiring oxygen and eliminating CO_2 from the body as a whole is called **respiration**.

Table 1.5: Different modes of respiration in animals

Animals	Respiratory organ
Unicellular animals like amoeba, planaria	Cell membrane
Earthworm	Skin
Aquatic animals like fish, prawns	Gills
Insects like grasshoppers, cockroaches	Spiracles and tracheae
Land animals like humans, birds	Lungs

Common features in respiratory organs

- All the respiratory organs have three common features:
  i. All the respiratory organs have a large surface area to get enough oxygen.
  ii. All the respiratory organs have thin walls for easy diffusion and exchange of respiratory gases.
  iii. All the respiratory organs like skin, gills and lungs have a rich blood supply for transporting respiratory gases.
- Terrestrial animals can breathe the oxygen in the atmosphere, but animals that live in water (aquatic animals) need to use the oxygen dissolved in water.
- Since the amount of dissolved oxygen is fairly low compared to the amount of oxygen in the air, the rate of breathing in aquatic organisms is much faster than that seen in terrestrial organisms.

1.9 Respiration in other animals

Respiration in Amoeba

- Amoeba is single-celled animal. Amoeba depend on simple diffusion of gases from breathing.
- The exchange of gases in amoeba takes place through its cell membrane.
- Amoeba lives in water. This water has oxygen dissolved in it. The oxygen from water diffuses into the body of the amoeba through its cell membrane.
- Since the amoeba is very small in size, the oxygen spreads quickly into its whole body.
- This oxygen is used for respiration inside the amoeba cell. The process of respiration produces carbon dioxide gas continuously. This carbon dioxide gas diffuses out through the membrane of amoeba into the surrounding water.

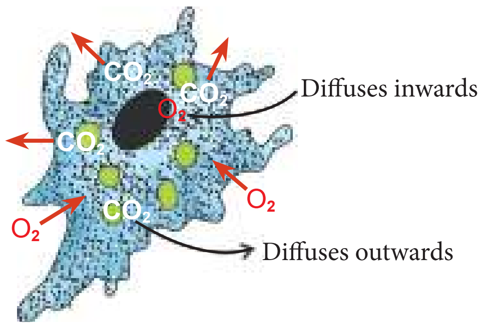


Fig. 1.24: Gaseous exchange in amoeba

1.10 Gaseous exchange in human beings and plants

Activity 1.14

1. Look at the cycle below with a friend.

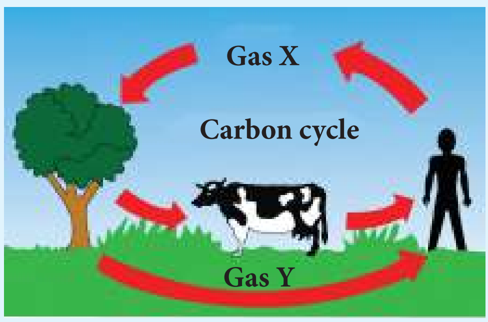


Fig. 1.25: Gaseous exchange cycle

2. What is the importance of the cycle shown in the diagram? Can you identify gases X and Y? What is their importance to each of the organisms represented in the cycle?
3. Based on the diagram, predict what you will learn in this unit.

The concept of respiration and respiratory surfaces

Respiration is the process where food taken in by organisms is burnt to produce energy required for their body functions. During respiration, oxygen is used and carbon dioxide is removed.

Cellular respiration takes place constantly in all living cells. It creates a constant demand for oxygen and a need to eliminate carbon dioxide gas. Gaseous exchange is the biological process through which these gases are transported through the body of an organism across a specialised respiratory surface. Organisms such as plants need to take in or release oxygen and carbon dioxide at one time or another during respiration and photosynthesis. Animals, on the other hand, always take in oxygen and release carbon dioxide during respiration. Gaseous exchange therefore is:

(i) Exchange of respiratory gases in animals.

(ii) Exchange of photosynthetic and respiratory gases in plants.

Therefore an efficient system for the exchange of gases is extremely important in living organisms. Gaseous exchange is necessary because organisms are able to obtain useful gases from their environment and get rid of waste gases into the environment.

The environments that organisms exchange gases with include: air for some organisms and water for others. Air is the main source of oxygen and carbon dioxide. Organisms that live on land exchange these gases directly with air. Oxygen and other gases from the air diffuse into lakes, rivers and oceans. The air dissolved in water is used for gaseous exchange by organisms that live in water.

Activity 1.15

Work in pairs

1. Find out about the following with a partner.
   (a) Respiratory surfaces
   (b) The gaseous exchange surface in man
   (c) The difference between cellular respiration and gaseous exchange
2. Write down answers in your notebooks.
3. Discuss your findings with your fellow classmates.

In large multicellular animals, the surface area to volume ratio is small. Many cells are deep inside the body of the animal, away from the surface. Diffusion of gases alone is not efficient enough in moving gases to and from all the cells. Therefore, large multicellular animals have specialised structures or organs with special surfaces over which gaseous exchange takes place. These special surfaces are called **respiratory surfaces**. Examples of specialised structures for gaseous exchange in animals include the following:

- Cell membrane

- Tracheal system in insects
- Buccal cavity in frogs
- Skin in frogs
- Gills in fish
- Lungs in mammals, birds, reptiles and amphibians.

Gaseous exchange takes place over the respiratory surfaces. A respiratory surface has a number of characteristics that make it efficient for gaseous exchange. Some of these characteristics include:

(i) Thin walls for faster diffusion of gases across it.

(ii) It is moist to dissolve gases as they diffuse across it.

(iii) It has a large surface area for maximum gaseous exchange.

(iv) In animals with a transport system, the respiratory surface has a rich supply of blood capillaries (highly vascularised) to quickly transport gases to and from the cells.

Not all respiratory surfaces are in direct contact with the medium through which gaseous exchange occurs, such as water or air around the organism. Therefore, there is need for a process that can ensure a continuous supply of fresh water or air to and from the respiratory surface. This is achieved by the process of **ventilation** which continuously brings water or air containing more oxygen to the respiratory surface. It also removes water or air containing a lot of carbon dioxide from it. Ventilation, therefore, is important because it maintains a high diffusion gradient at the respiratory surface. It also ensures a high rate of gaseous exchange. Breathing is an example of ventilation.

The mechanism of breathing in humans

In human beings, the process of breathing (ventilation) is the first part of the gaseous exchange processes. The second part is the exchange of these gases between the lungs and blood. Breathing provides a continuous supply of fresh air to the gas exchange surface. It also helps to maintain a large diffusion gradient across the gas exchange surface. The volume of gases exchanged during breathing changes according to physiological demands placed on the body, for example, during an exercise. The breathing rate is controlled by the respiratory centre of the brain.

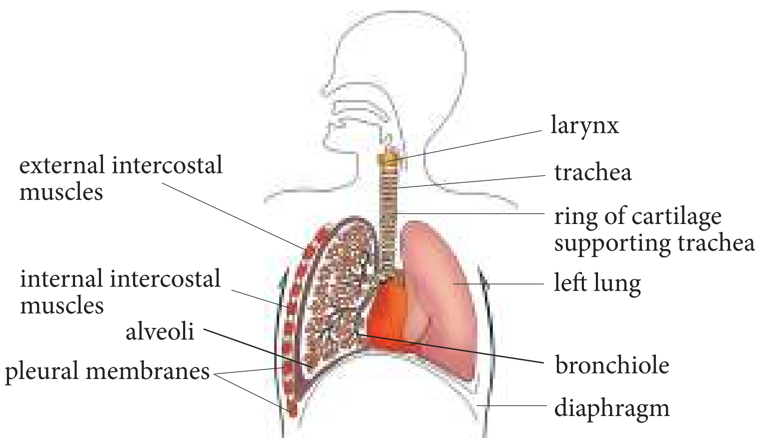


Fig 1.26: Human breathing system

Activity 1.16: To observe the movement of the chest during breathing

Work in pairs

Carry out the following exercise.

1. Ask your partner to breathe in deeply then hold their breath.
2. Place your hand on his or her ribcage and feel the movement of the ribs and the expansion of the chest cavity.
3. Describe what you see happening to the chest as your partner breathes in.
    - Does it remain in the same position?
4. Let your partner now breathe out.
    - What do you see happening to the chest?
5. Record the form of movements noticed.

The facts

The process that brings air into the lungs and removes it again is known as breathing. Breathing involves two phases called **inhalation** and **exhalation**. Since the lungs contain no muscle tissue, they are not capable of independent movement. However, they are elastic, and during breathing they are forced to expand or contract as a result of pressure changes around them. These pressure changes are caused by the movement of the muscular diaphragm, ribs and intercostal muscles (rib muscle), and by the force of atmospheric pressure.

Activity 1.17: Construction and use of a model to demonstrate breathing mechanism

Work in groups

Materials

- Bell jar
- Two balloons
- Rubber stopper with a hole
- Shaped glass tube
- Rubber sheet and rubber band
- String

Procedure

1. Assemble the materials as shown below.

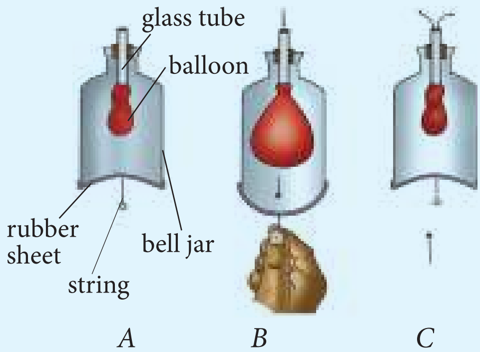


Fig 1.27: Breathing model

2. Study the model and state what the following parts represent in the human respiratory system
    - Bell jar
    - Balloon
    - Rubber sheet
3. Pull down the rubber sheet at the bottom of the bell jar.
    - What happens to the balloon?
4. Now push up the rubber sheet.
    - What happens to the balloon?

Study questions

(a) Draw sketches to show the appearance of the balloon in (2) and (3) above.
(b) Explain your observation.
(c) Explain how the model is similar to the working of the thorax in human beings during breathing.

a) Inhalation (breathing in)

Inhalation is also known as inspiration. This is the active phase of breathing which draws air into the lungs. During inhalation, the diaphragm muscles contract causing it to flatten, as in Fig. 1.28. In the ribs region, the external intercostal muscles contract while the internal intercostal muscles relax. This causes the rib cage to move upwards and outwards.

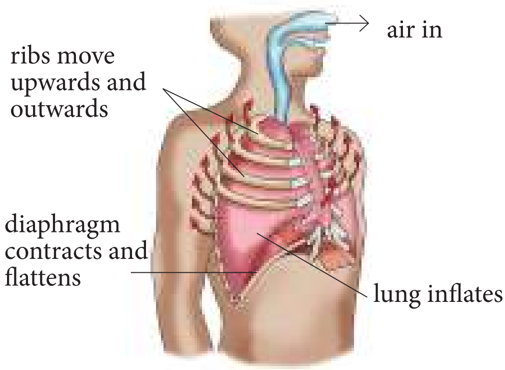


Fig 1.28: Inspiration (inhalation)

The contraction of the diaphragm and external intercostal muscles increases the volume in the chest cavity. However, it causes a decrease in the pressure of air inside compared to atmospheric air. Air rushes through the air passages into the lungs, forcing them to expand.

b. Exhalation (breathing out)

Exhalation is also known as expiration. This is the phase of breathing, which expels air out of the lungs. During exhalation, the diaphragm muscle relaxes making it move upward and regain its dome shape. The external intercostal muscles relax and the internal intercostal muscles contract. This causes the rib cage to move downward and inwards. The volume of the chest cavity decreases and the pressure increases compared to the atmospheric air. Increased pressure forces air out of the lungs, which become deflated.

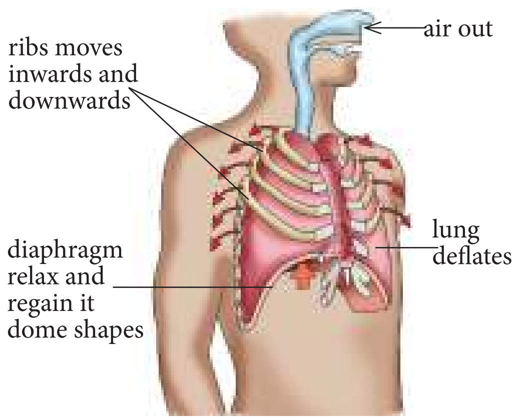


Fig 1.29: Expiration (exhalation)

Table 1.6: Difference between inhalation and exhalation

Inhalation	Exhalation
1. External intercostal muscles contract. Internal intercostal muscles relax.	1. External intercostal muscles relax. Internal intercostal muscles contract.
2. Rib cage moves upwards and outwards.	2. Rib cage moves downwards and inwards.
3. Diaphragm muscles contract and diaphragm flattens.	3. Diaphragm muscles relax and diaphragm forms a dome shape.
4. Volume of the thoracic cavity increases.	4. Volume of the thoracic cavity decreases.
5. Air pressure in the lungs and thoracic cavity decreases compared to external atmospheric pressure.	5. Air pressure in the lungs and thoracic cavity increases compared to external atmospheric pressure.
6. External air is driven into the lungs due to the pressure difference between the inside and the outside.	6. Air in the lungs is compressed and forced out.
7. Lungs inflate	7. Lungs deflate

Activity 1.18: Dissection of a small mammal to display the structures of the respiratory system

Work in groups

Materials

- Dissection board
- Pins
- Scissors
- Scalpels
- Cotton wool
- Rat or rabbit (freshly killed)
- Forceps
- String
- Rubber pipette
- Gloves

Procedure

Your teacher will carry out a demonstration on how to dissect a small mammal using the steps provided. Follow the demonstration carefully and then use the steps provided in the procedure to dissect a small mammal in groups.

1. Pin the animal onto the dissection board with the ventral side up.
2. Open the thorax by cutting with scissors along the middle from the neck to the hind legs.

Fig 1.30: Internal parts of a dissected mammal

3. Tie a string round the xiphoid cartilage. Pull the string back so as to stretch the diaphragm. Note the following.
   - Muscles of the diaphragm
   - Intercostal muscles between the ribs
   - Lungs
4. Remove the lungs out and place them on the board.
   - How does it feel when touched?
5. Cut through the lungs.
   - What do you see?
6. Identify the main airways.
7. Note your observations.
8. Share your findings with the class.

Gas exchange in the alveoli

Air passes the nose or mouth as it moves down the trachea. The trachea is divided into the left and right bronchi. Each bronchus is divided into smaller bronchioles and each bronchiole is in turn attached to numerous alveolar sacs. The groupings of alveoli take the same shape like a bunch of grapes.

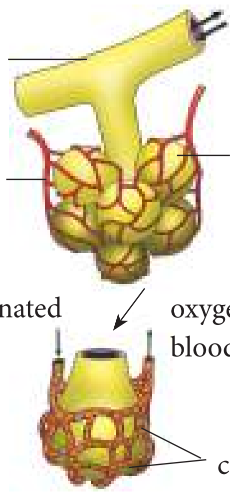


Fig 1.31: Alveoli

Gaseous exchange at the alveolus takes place between the phases of inhalation and exhalation. The alveolus is a suitable point for gaseous exchange because:

- It is supplied with blood which carries the gases being exchanged.
- It has a very thin wall across which gases diffuse between it and the blood.
- It is lined with a thin film of moisture to dissolve the diffusing gases.
- A ventilation process brings in and takes away air containing the gases being exchanged.
- It has a very large number of alveoli to increase their surface area for gaseous exchange.

Gas exchange between the air within the alveoli and the pulmonary capillaries occurs by diffusion. Oxygen in air, in the alveolar space is at a higher concentration than that in the blood capillaries. It therefore first dissolves in the water layer in the alveolar lining then diffuses across the alveolus and then the capillary walls and into the red blood cells. This becomes oxygenated blood which is carried to the heart by the pulmonary vein.

Carbon dioxide in the blood diffuses across the capillary and alveolus walls into the alveolar space and is eventually expelled during exhalation.

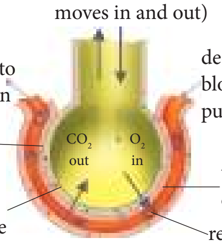


Fig 1.32: Gaseous exchange in the alveolus

A diffusion gradient is essential for rapid gaseous exchange in the alveolus. The following factors contribute towards maintaining this diffusion gradient.

(a) **Lung ventilation:** Breathing movements transport respiratory gases to and from the alveolus.

(b) **Blood flow:** This constantly replaces oxygenated blood with deoxygenated blood. The pulmonary artery brings blood low in oxygen concentration and high in carbon dioxide concentration. The pulmonary vein takes away blood high in oxygen concentration and low in carbon dioxide concentration.

(c) **Haemoglobin:** It quickly combines with oxygen and prevents its accumulation in the alveolus.

Activity 1.19: To analyse the gas present in exhaled air

Work in groups

Materials

- Conical flask
- Couch
- T-tube
- L-tube
- Limewater
- Delivery tube

Procedure

1. Set up the apparatus as shown in the diagram below.

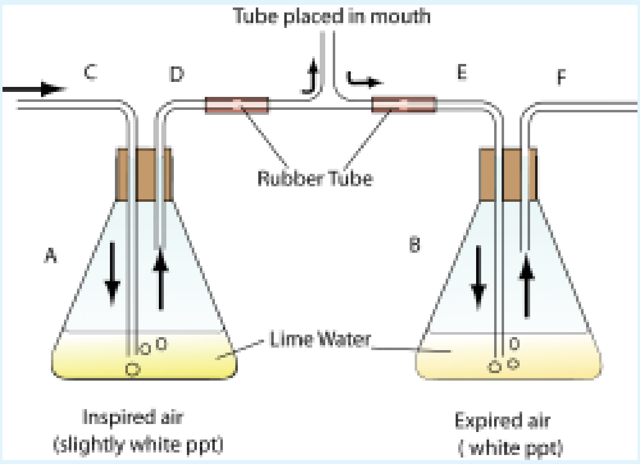


Fig 1.33: Setup for investigating a gas present during exhalation

2. Breath in and out through the mouth.
3. What do you notice in the lime water in:
   - Flask A?
   - Flask B?
4. Explain your observation in:
   - Flask A
   - Flask B
5. How else can the experiment be designed?

The facts

Table 1.7: Composition of inhaled and exhaled air

Component of air	Inhaled (air) %	Exhaled (air) %
Oxygen	21	15
Carbon dioxide	0.04	4
Nitrogen	79	79
Bacteria	Low count	High count
Water vapour	Variable	Saturated

Task: From the table above, explain the difference in composition of gases in inhaled and exhaled air.

1.11 Gaseous exchange in plants

The principal gaseous exchange surfaces for plants are the leaves. Plant leaves have stomatal pores on their surface where gaseous exchange occurs. Plants do not have a specialised respiratory system like animals. This is because they are metabolically less active than animals.

Activity 1.20: To demonstrate the presence of stomata in leaves

Work in groups

Materials

- Plant leaves (e.g. Peace Lily, *Spathiphyllum*)
- A bottle of clear or colourless nail polish
- A clear cellophane tape (or clear packing tape)
- Microscope slides
- Scissors
- Microscope

Procedure

1. Paint a 1 cm^2 (or larger) square of thick nail polish on the underside surface of the leaf being studied. Allow the nail polish to dry fully.
2. Once the patch of nail polish is dry, tape a piece of clear cellophane tape to the patch on the leaf.
3. Carefully pull on a corner of the tape and gently peel the nail polish off the leaf.
   The layer of cells that sticks on the nail polish is what you will examine under the microscope.
4. Tape the peeled nail polish and its layer of cells to a clean microscope slide, using scissors to trim any excess tape.
   - The teacher will help you predict and explain the different types of cells that you see and how to find the stomata.

5. Place the slide on the microscope stage. Using the low power objective lens, focus the slide until the stomata are visible.

   Each stoma is bordered by two sausage-shaped cells, called guard cells, which are normally smaller than epidermal cells. Unlike other cells in the epidermis, guard cells contain chloroplasts.
6. Sketch what you observe under the microscope, labelling the stoma, guard cells, epidermal cells and chloroplasts.
7. Count the number of stomata in your field of view, then estimate the number of stomata on the sample being examined.

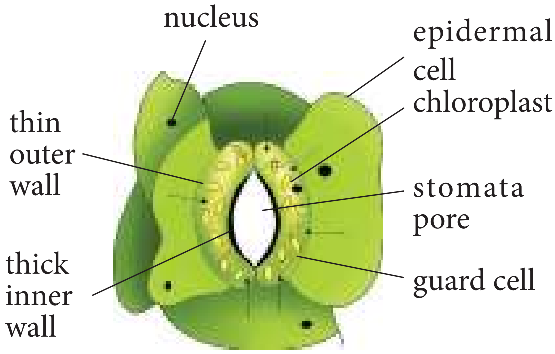
The facts

Stomata are pores between guard cells. They are found on the upper or lower epidermis or both. Stomata allow:

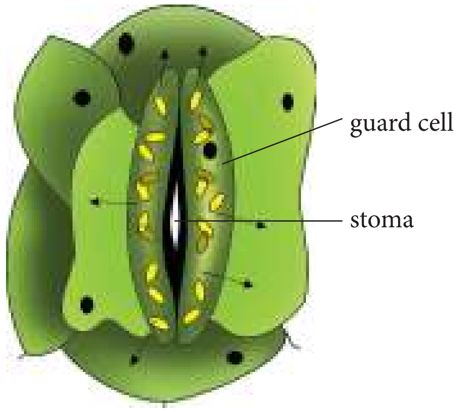
- Entry of carbon dioxide into the leaf for photosynthesis.
- Exit of oxygen.
- Evaporation of water.

Stomata are the main structures for gaseous exchange in leaves of plants. They are tiny openings found in the epidermis of leaves. With the exception of submerged plants, stomata are present in all the leaves of plants. Most land plants have stomata on the lower surface of the leaf.

Stomata allows gaseous exchange to take place in leaves. Let us examine the structure of stomata to understand how gaseous exchange takes place through them.



(a) Open stoma



(b) Closed stoma

Fig 1.34: Open and closed stomata

The guard cells control the opening and closing of each stoma.

Discussion corner

1. Discuss the following questions with some of your classmates.
   a) How does gaseous exchange occur in plants?
   b) Relate gaseous exchange in plants and animals.
2. Share your findings with the rest of the class.

The facts

The leaf epidermis has pores (stomata) and internally the spongy mesophyll has air spaces containing air. When the leaf is placed in hot water, the air expands and escapes through the stomata forming air bubbles on the leaf surface in water. There are normally more stomata on the lower side than the upper side as shown by the bubbles.

When the stomata are open, air from the surrounding enters the leaf and occupies the air spaces. Oxygen and carbon (IV) oxide diffuse into or out of the leaf cells along a concentration gradient.

During photosynthesis, carbon (IV) oxide is used up by the cell and oxygen is produced.

This means that the concentration of carbon (IV) oxide in the cells becomes lower than in the air spaces outside the cells. Therefore during photosynthesis carbon (IV) oxide diffuses into the cells.

Photosynthesis produces oxygen whose concentration becomes higher inside the cells than in the air spaces surrounding the cells. Oxygen therefore diffuses out of the cell into the air spaces. This is the process of gaseous exchange in leaves.

Gases first dissolve in the film of moisture surrounding the cell before they diffuse into or out of the cell. Note that when air is entering or leaving the plant through stomata, the process is not gaseous exchange but diffusion. Gaseous exchange refers to the movement of gases between the cells and their surrounding.

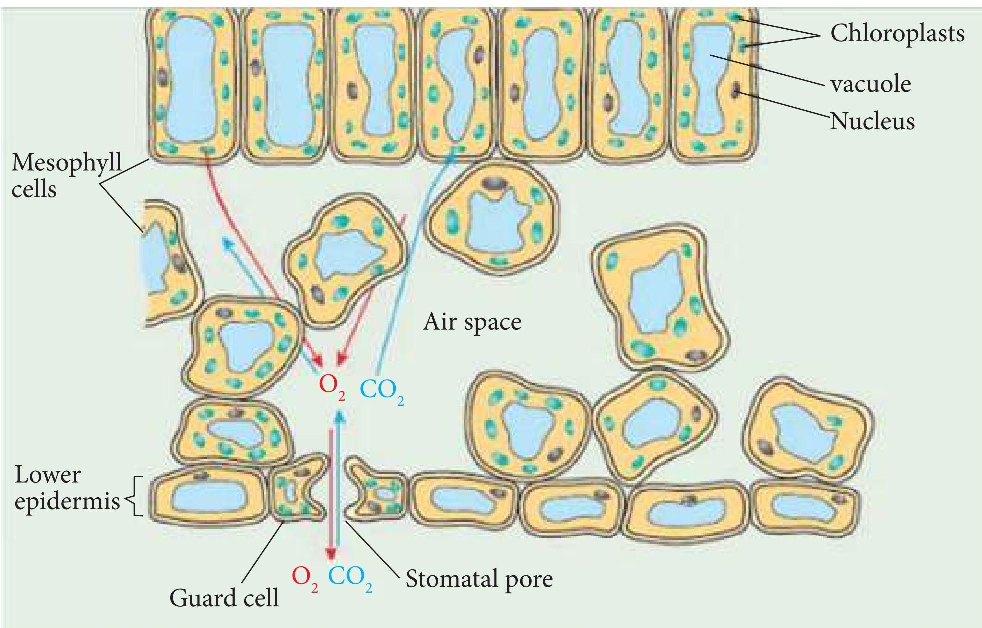


Fig 1.35: Gaseous exchange in the leaf of a terrestrial plant

Stems of woody terrestrial trees and shrubs have areas of loosely arranged cells with large air spaces between them. These cells together form a structure called a **lenticel**. Lenticels are formed when the epidermis is replaced by the bark. Lenticels appear scattered on the surface of the stem as small raised openings. They allow gaseous exchange of oxygen and carbon (IV) oxide between the atmosphere and the internal tissues of the stem.

Check your progress 1.6

1. What are the structural differences between guard cells and other epidermal cells?
2. Although the leaves are the main organs of gaseous exchange in plants, the roots also absorb oxygen in the soil. Why is this necessary?

Gaseous exchange in aquatic plants

Photosynthesis in completely submerged wetland plants is severely impeded by low light and the slow diffusion of CO_2 across the aqueous diffusive boundary layer (DBL) adjacent to leaves.

Hydrophytes are plants that are well adapted to survive in or on water logged areas. Examples include lotus, sea weeds and water lily. Common adaptations are to increase the rate of gaseous exchange.

Fig. 1.36: Water hyacinth is an example of on aquatic plant

Hydrophytes have the following features to increase water loss:

- The epidermal layer has little cuticle, as water loss is not a problem. All the surface cells appear to be able to absorb water, nutrients and dissolved gases directly from the surrounding water.
- The vascular bundles are often greatly reduced.
- The root system is very much reduced in some floating plants and in submerged plants the roots are absent.
- In some aquatic plants the stems are long, slender, soft and spongy which can bend easily in each and every direction.
- The submerged leaves are often highly dissected or divided to create a very large surface area for absorption and photosynthesis. The emergent leaves are much less divided.

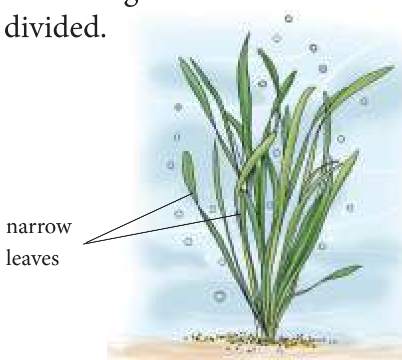


Fig. 1.37: Submerged leaves of Vallisneria gigantea

- Stomata are mostly found only on the upper surface of the leaf. This upper surface often has a thick waxy cuticle to repel water and help to keep the stomata open and clear.
- Presence of aerenchyma tissues that allow diffusion of oxygen from the aerial portions of the plant into the roots.

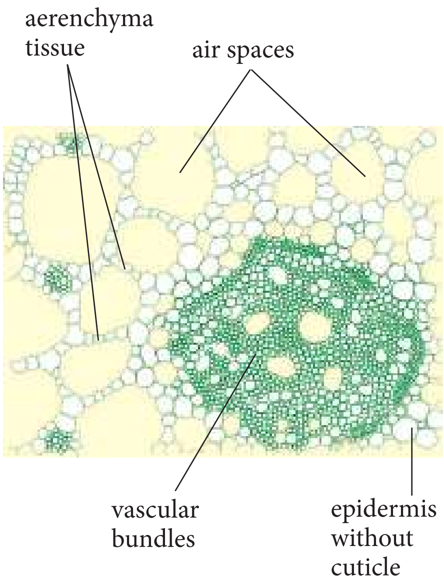


Fig. 1.38: Cross-section through hydrophyte leaf showing aerenchyma tissue

Check your progress 1.7

1. Suggest why organisms develop gaseous exchange systems.
2. Briefly explain a series of events that take place during calm breathing.
3. Do you think the government of South Sudan should ban the sale of cigarettes? Explain.
4. Explain how you would help a person who has just had an asthma attack.
5. How does exercise affect the breathing rate?
6. Two leaves were immersed in a beaker containing warm water. Bubbles of a gas were observed to form and escape from the leaf surfaces. In leaf A, bubbles formed on both surfaces but more on the lower surface than on the upper surface. In leaf B, very many bubbles formed on the upper surface but none on the lower surface.
   (a) What does the production of bubbles depict about the leaf surfaces?
   (b) What does the production of bubbles indicate about the internal structure of the leaf?
   (c) Suggest the possible habitats of the leaves A and B.
7. The atmospheric air contains 79% nitrogen and 20% oxygen. Explain why we breathe in oxygen and not nitrogen which is abundant.

Unit 2

Reproduction and growth in plants and animals

Learning outcomes

Knowledge and understanding	Skills	Attitude
• Detail the processes of reproduction in plants and animals.	• Investigate the reproductive features of several flowers to compare the sexual process and observation of gametes. • Design investigations on asexual reproduction in plants and the factors effecting germination and growth. • Investigate the stages of mitosis. • Investigate insect and wind pollinated flowers and relate structure to function. • Collect, classify and dissect fruits and seeds and relate their structure to mode of dispersal. • Study embryo development of hen's eggs.	• Appreciate reproduction in plants and animals. • Appreciate the diversity of life in both plants and animals.

Introduction

A seed is so small compared to a tree. What makes it germinate and grow into a seedling then into a big plant? Similarly, how do animals produce live young ones? How do young ones grow over time?

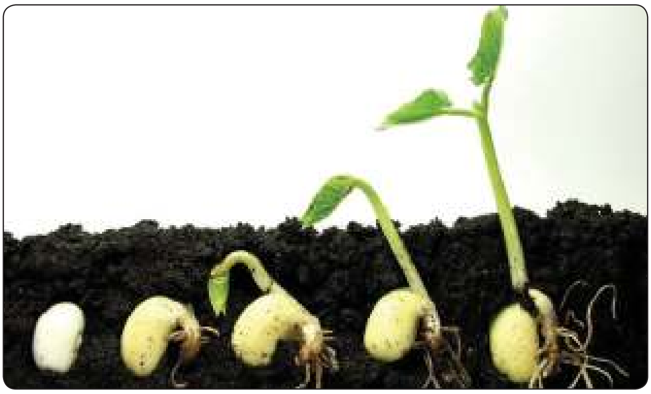


Fig 2.1 a: Germinating seedling

Fig 2.1 b: A cow and its young one

2.1 Asexual reproduction in lower organisms

Living things reproduce either asexually or sexually and these forms of reproduction involve a process of cell division. In asexual reproduction, the type of cell division that occurs is **mitosis**. It is a primitive form of reproduction that occurs in lower organisms.

In sexual reproduction, cell division is mostly by **meiosis**. It is responsible for the formation of new cells which may:

- form new organisms.
- form parts of the organisms that may break off to form a new organisms, for instance buds form structures such as spores which are released from the organisms and eventually develop into new organisms.

Asexual reproduction in microorganisms

Activity 2.1: To observe forms of asexual reproduction in microorganisms

Work as a group

Materials

- Charts and diagrams
- Computer animations

Procedure

1. By observing the computer animations, charts or diagrams given:
    - What type of reproduction is shown?
    - Are the organisms reproducing alone or in pairs?
    - Are the offspring produced similar to the parent(s)?
2. Discuss your results and present your work to the rest of the class.

The facts

Asexual reproduction is the mode of reproduction that results in formation of genetically identical offspring from the same parent. It takes place when offspring are formed from a single organism or parent without the formation of gametes.

In this type of reproduction, the offspring are duplicates of the parent. This means that they are completely identical in appearance and structural make-up to their parents.

In asexual reproduction, parts of the mature organism may develop into a new individual. One or more cells from the parent may also separate and develop into a new individual. The type of cell division that occurs in asexual reproduction is called **mitosis.** It is responsible for the formation of new cells. Asexual reproduction is important because it is responsible for reproduction in organisms like *mucor, amoeba,* yeast, *Rhizopus* among others. Asexual reproduction results in rapid production of genetically identical offspring.

Types of asexual reproduction

(a) Binary fission

Binary fission is a form of asexual reproduction. It occurs in single-celled organisms like *amoeba,* bacteria and *paramecium*. The word **'binary'** means two and **'fission'** means splitting.

(i) Binary fission in bacteria

Most bacteria rely on binary fission for propagation at a favourable time. The nucleus of the parent cell first divides followed by the cytoplasm resulting in the formation of two daughter cells that are identical to the parent cell. The daughter cells increase in size and mature. They will also undergo binary fission. All these processes are controlled by the nucleus.

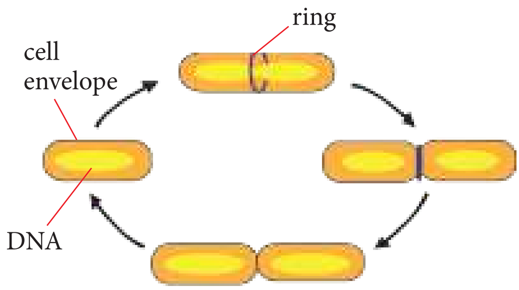


Fig 2.2: Binary fission in bacteria

One difference between fission and budding in bacteria is that in the latter, the mother cell often has different properties from the offspring.

(ii) Binary fission in amoeba

When *Amoeba* reproduces, it divides to form two cells. Each cell becomes a separate organism capable of existing on its own. First, the nucleus inside the cell divides followed by division of the cytoplasm and then the entire cellular components of the organism.

Did you know?

Two new cells are therefore formed from the original parent cell. These cells are described as daughter cells because they are produced by the mother cell.

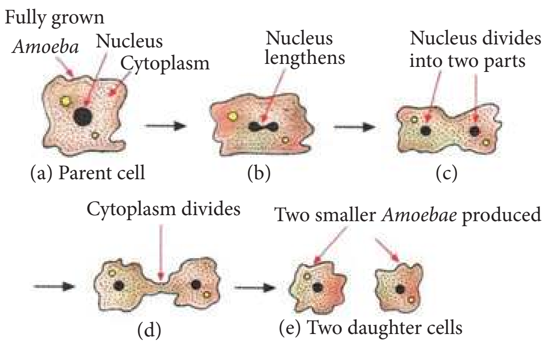


Fig 2.3: Binary fission in amoeba

(b) Budding

This mode of asexual reproduction occurs in fungi like yeast. The parent organism forms an outgrowth or protuberance called a **bud.** This bud enlarges and takes on the shape and appearance of the parent. The nucleus of the parent cell divides into a daughter nucleus and moves into the daughter cell. The daughter cell continues to grow until it eventually breaks away from the parent cell and survives as an independent cell. Once it grows and matures, it produces another organism by budding.

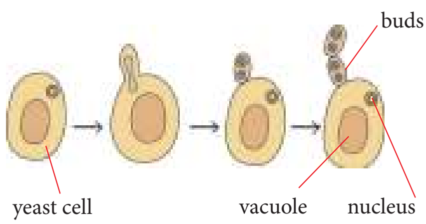


Fig 2.4: Budding in yeast

Under favourable conditions that are warm and have enough nutrients, yeast cells bud rapidly.

(c) Spore formation

Activity 2.2: Examining spores in sori of a fern

Work as a group

Materials

- Leaves or fronds from a mature fern
- Hand lens
- Slides
- Coverslips
- Pins
- Water
- White tile

- Scapel
- Microscope

Procedure

1. Examine the fern plant.
2. Note that the leaves or fronds are subdivided into leaflets.
    - Look for the leaflets that have brown round structures on their underside.
    - The brown round structures are called sori (singular: sorus). They form a cover over the spore cases or sporangia.
3. Cut off the leaflets with sori and place them on a tile with the sori on the upper side.
4. Using a pin, remove a sorus from one of the leaflets.
5. Using a hand lens, study the underside of the sori. What can you see?
6. Using a needle, remove the structures that are in the sori. These are sporangia or spore capsules.
7. Place them on a cover slip and put a drop of water on a slide to cover the sporangia.

    Place a cover slip over them and press gently. Observe them under the low power of a microscope.
8. Draw what you observe.
9. Look out for sporangia that have split open and released spores.

Study questions

1. What is the name given to leaflets on a fern plant?
2. Name the structures found on the underside of the leaflets that produce spores.
3. What is the name given to the spore capsules that contain the spores?
4. What do you think is the role of the spore once it is released from the sporangium?

The facts

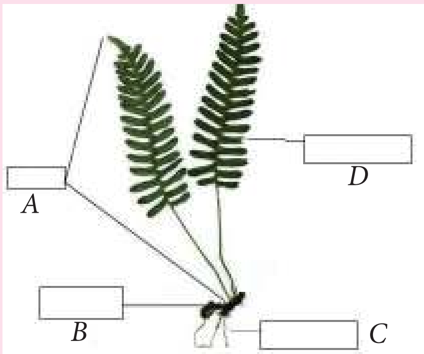
Spores in ferns are found in structures called sporangia. The sporangia are found in structures located on the underside of leaflets in structures called sori (singular: sorus). At maturity, sori appear brown due to an umbrella shaped structure that covers them.

Spores are released when they are mature by the bursting of the sporangium. They are dispersed by wind and water or on the surface of organisms like insects to suitable ground where they germinate and grow into new ferns. The diagram below shows the position of sporangia in the fern.

Fig 2.5: Spores in fern

Check your progress 2.1

1. Briefly describe how amoeba produces.
2. The diagram below shows a fern.



Fill in the blank spaces in the boxes.

3. What is the role of rhizoids?

2.2 Asexual reproduction in plants

Activity 2.3: To observe forms of asexual reproduction in plants

Work as a group

Materials

Vegetative materials such as:

- Sugarcane cuttings
- Potato tubers
- Yams
- Grass rhizomes
- Banana suckers

Procedure

1. Examine each specimen provided carefully.
   - Note the parts where food substances are stored.
   - Note the parts in the structure that are involved in reproduction.
2. Draw and label each of the specimens provided.
3. Genetic engineering has contributed to improvement. Justify.
4. How will you know that there is no variation in plants produced through genetic modification? Explain.

The facts

Vegetative propagation is a form of asexual reproduction in plants in which multicellular structures become detached from the parent plant and develop into new individuals that are genetically identical to the parent plant. It can occur naturally or be induced by man (artificially). Plants survive from one germinating season to another under unfavourable conditions such as drought or winter. They develop **perennating organs** which store enough nutrients to sustain them during such periods.

Common forms of perennating organs are, for example, tubers, rhizomes and buds. Perennation is closely related to vegetative reproduction as the organisms commonly use the same organs for both survival and reproduction.

Natural methods of asexual reproduction include strategies that plants have developed to self-propagate. Plants use vegetative materials which are parts of the plants other than seeds that can be used to produce new individual plants. The vegetative parts or structures have the ability to develop new shoots and roots.

Many plants, such as ginger, onion and dahlia, continue to grow from buds that are present on the surface of the stem. In some plants, such as the sweet potato, adventitious roots or runners (stolons) can give rise to new plants. When these parts are detached from the plant, they grow into independent plants. Some plants may also start growing into independent plants if the leaf touches the soil. Other plants can be propagated through cuttings alone.

Examples of vegetative plant parts are:

(i) Cuttings e.g. tea

(ii) Suckers e.g. banana

(iii) Crowns e.g. pineapple

Plant parts used for vegetative propagation

Vegetative propagation is used in the growing of many crop plants. Some of these plant parts are storage organs such as **bulbs**, **rhizomes**, **corms**, **tubers** and **suckers**.

(a) Bulb

This is a short modified underground stem with nodes bearing fleshy scale leaves surrounded by some dry scale leaves. The internodes of the stem are close to each other so that leaves overlap tightly over each other. Buds arise in the axils of the fleshy scale leaves. The food is stored in the fleshy scale leaves and not in the stem. Adventitious roots are found at the base of the stem. Examples of bulb crops are onion, garlic and tulip.

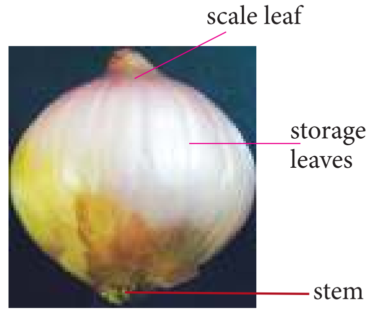


Fig 2.6: Onion bulb

(b) Stem tuber

This is a swollen tip of an underground stem bearing a number of reduced scale leaves. Each scale leaf surrounds the 'eye' of the tuber. The eye is actually the bud. The buds produce aerial shoots and adventitious roots grow at the base. Examples include the Irish potato and yams.

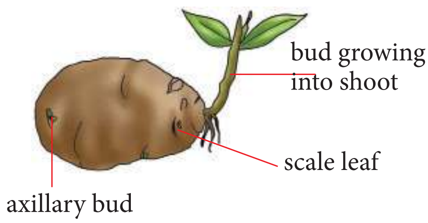


Fig 2.7: Irish potato tuber

Some tubers have swollen roots, which are called **root tubers**. Examples of root tubers are sweet potato, cassava and dahlia.

(c) Suckers

These are lateral branches of a stem with terminal buds at the tips. They grow from the base of the underground stem just beneath the soil surface. New shoots grow along the sucker with adventitious roots developing below the stem. Examples of plants produced by suckers are banana and sisal.

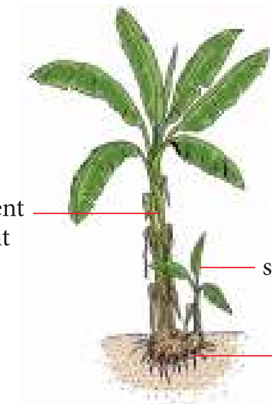


Fig 2.8: Suckers

(d) Rhizomes

These are horizontal underground stems which possess thin scale leaves and buds. In some plants, adventitious roots are present. Examples of plants with rhizomes are edible canna lily, ginger and turmeric.

Rhizomes are used to store starch and proteins and enable a plant to survive an annual unfavourable season underground. In plants such as water lily and many ferns, the rhizome is the only stem of the plant. In such cases, only the leaves and flowers are readily visible. Notably, the rhizomes of some species including ginger, turmeric and lotus are edible.

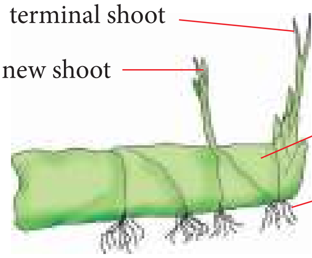


Fig 2.9: Rhizome

Artificial propagation

Artificial vegetative propagation does not occur naturally. These are ways in which human beings influence the production of a new plant from another so as to get a desired offspring. This type of propagation may be carried out in order to get healthier plants, desired traits and/or a more rapid efficient production rate of offspring or for general experimentation. Methods of artificial propagation include **grafting**, **cutting** and **budding**.

(a) Grafting

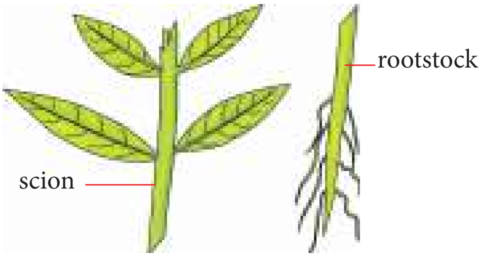
Grafting is the art of joining two parts of plants together in such a manner that they will unite and continue their growth as one plant. The part of the grafting combination, which is to become the upper portion of the new plant, is termed as a **scion** and the lower portion that forms the root is called a **rootstock**.

Scion is the short piece of detached shoot containing several dormant buds which forms the upper portion of the graft that grows into shoots or branches of the grafted plant. The stock (root stock) develops into the root system of the grafted plant.

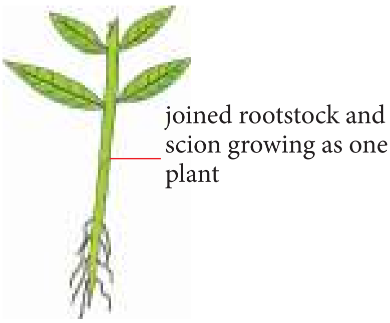
Reasons for grafting

1. Increased productivity i.e production of multiple fruits.
2. The new plant is resistant to bacteria, soil nematicles and viruses.
3. Grafting leads to genetic improvement of new plants as opposed to the former plants.

Grafting is commonly used in propagation of citrus fruit varieties such as sweet orange, rough lemon, sour orange, grape fruit, trifoliate orange, citranges, among others. In grafting, good rootstocks must be carefully selected.



(a) Before grafting



(b) After uniting scion and rootstock

Fig 2.10: Grafting

(b) Cuttings

Cuttings can be developed from stems or roots. Stem cuttings or sections of the stalks called setts or seed pieces propagate, for example in sugarcane cuttings. Each sett contains one or more buds. Stem cuttings can be either raised in the nursery, e.g. in tea, or planted directly in the field, e.g. in sugarcane. Most cuttings for perennial crops are obtained from the hard section of the plant part, e.g. tea cuttings. For sugarcane setts, cuttings are usually taken from the soft upper parts of the shoot.

Stem cuttings are obtained from healthy parent plants which are high yielding, healthy and have rooting ability.

(i) *Single-leaf stem cuttings for tea propagation:* These are obtained from the middle part of stems of selected mature trees, then planted in polythene sleeves filled with rooting medium. They are then placed in a nursery. High relative humidity must be maintained for their rapid growth and development.

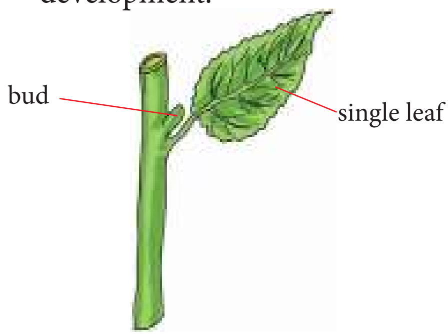


Fig 2.11: Single leaf stem cutting of tea

(ii) *Setts for sugarcane propagation:* Sizeable cuttings are planted directly in the seedbed. Setts with three nodes are prepared and subjected to heat treatment or treated with an organo-mercurial fungicide against ratoon stunting disease. Each sett usually measures 30 - 45 cm long.

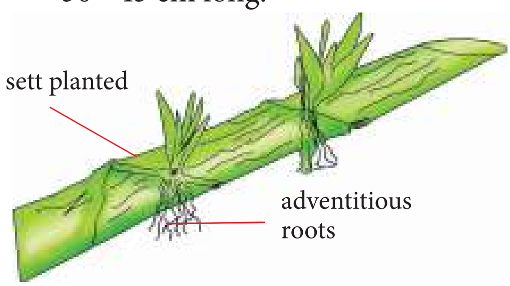


Fig 2.12: Stem cutting of sugarcane

Check your progress 2.2

1. Distinguish between sexual and asexual reproduction.
2. In binary fission, how does the DNA of the daughter cells compare to the DNA of the parent cell?
   A) It has some similarities and some differences.
   B) It is only half of the amount of DNA found in the parent.
   C) It is identical.
   D) It is a mix of the parent's DNA.
3. How can asexually reproducing organisms gain some genetic diversity?
   A) Meiosis
   B) Mitosis
   C) Crossing over
   D) Mutations
4. What are the benefits of artificial propagation to man?
5. What was the genetic relationship of vegetatively propagated offspring compared to their parents?

Further activity

Research from the internet or any other reference material on why vegetatively propagated plants produce genetically identical offsprings which are identical to their parents as opposed to humans.

Advantages and disadvantages of asexual reproduction in plants

Activity 2.4: Research Activity

Work as an individual

1. Use the internet and text books in the library to do a research on the advantages and disadvantages of asexual reproduction.
2. Present your findings to the rest of the class.

Advantages of asexual reproduction

1. It is a simple procedure that requires less energy compared with sexual reproduction. Organisms that reproduce asexually do not have to carry their offspring (gestate), and produce more than one at a time. This makes it a quick and inexpensive process for them in terms of time.
2. It allows for different organisms to have the ability to take different forms. This allows them to successfully produce offspring in various environments.
3. It enables organisms to produce large quantities of offspring. This fast reproduction checks intruders and competition from invading species. There are also better chances of survival when conditions change and the number of predators increase.
4. Finding a mate can be very difficult

for organisms that are in isolated environments, for example, the deep ocean. Asexual reproduction takes the need to find a mate away, allowing these organisms to multiply. This is important especially when colonising new areas.

5. It does not need mobility. Therefore, organisms that often stay in one place do not need to move to other places just to produce offspring.

Disadvantages of asexual reproduction

1. **No diversity.** In this type of reproduction, the offspring produced are genetically identical to each other and to the parent. This causes no or very little genetic variation within a population. Therefore, there is no diversity among the population of these organisms. This leads to more unfavourable mutations to asexually produced organisms that are susceptible to diseases and may lead to a huge number of organisms being destroyed.
2. **They are prone to extinction**. Having the same traits also means having the same weaknesses. Parasites and other predators that have evolved to kill just one of the organisms can take out the entire population. It requires a single asexual parent, from which the chromosomes and genes are copied. This means the genetic mutations or defects which are bred out would be present in the offspring. Any mutation in the parent cell can cause harmful effects on the survival ability of the offspring.
3. This form of reproduction has no control over the rapid increase of the population of the organisms. There might be the risk of food and space competition. This usually leads to the struggle for existence and overcrowding within the community.

Activity 2.5: Investigating asexual reproduction in Irish potato tubers

Work as a group

Materials

- Plastic cups
- Toothpicks
- Water
- Potatoes

Procedure

1. Pour water in the plastic cups.
2. Place potatoes in the plastic cups with water using toothpicks to hold them.
3. Change water often and after sometime observe the changes on the potatoes.

Study questions

1. What observations did you make on the potatoes after sometime?
2. Which kind of reproduction is this?

The facts

After sometime, roots and shoots will sprout out from the potatoes. Potatoes when exposed to favourable conditions, will reproduce asexually.

Check your progress 2.3

1. Ability of many offspring to be produced through asexual reproduction is also disadvantageous. Explain.
2. Why is population control an issue in any species?
3. How is asexual reproduction important?

Sexual reproduction in plants

Flowering plants are the most abundant and widespread group of plants on earth. They are found in most habitats, from deserts to polar-regions. They include species of trees, shrubs and herbs. The flowers are the reproductive structures that produce new plants. Reproduction in flowering plants, as in animals, involves the fusion of male and female gametes in a process known as **fertilisation**. After fertilisation, **seeds** are formed which germinate into new plants.

A flower may have both male and female structures hence the term **bisexual** flower, or it may have structures of one sex only, thus a **unisexual** flower. A complete flower will have all parts while an incomplete flower will lack some parts. Flowers which are **insect** pollinated are brightly coloured while **wind** pollinated flowers are usually dull. Flowers need to be protected to ensure continuity of a species and to protect biodiversity.

2.3 Structure of a flower

Flowers are structures for sexual reproduction. There are many different types of flowers with great variation in size, colour and floral parts. Some plants have flowers whose structures are suited for pollination by insects. These are insect pollinated flowers for example, *Hibiscus*. Other plants have flowers that are suited to wind pollination. These are wind pollinated flowers. Examples are grass and maize flowers.

Activity 2.6:Examining various types of flowers

Work as a group

Materials

- Hand lens
- Notebook
- Pencil
- Various flowers

Procedure

1. Collect a variety of flowers from the school compound.

   Caution: Do not destroy any plants.
2. Examine each flower carefully using a hand lens.
3. Draw and label it as fully as you can.
4. For each flower, note the following points in your notebook:
   - Name of the flower (ask your teacher for assistance).

- Number and colour of the sepals. Are they fused or separate?
- Number, colour and size of petals. Are they fused or separate?
- Number and arrangement of stamens.
- Position and shape of the stigma.
- Presence or absence of scent.

Caution: If you are asthmatic or allergic to pollen, do not smell the flowers.

Study questions

1. How can you describe the appearance of each of the flowers you have observed?
2. What is the general arrangement of the floral parts (flower parts)?
3. Did you notice insects visiting some of these flowers? Why do you think some flowers were visited by insects while others were not?
4. Discuss with your friends the functions of parts of a flower.
5. How is the plant adapted to insect pollination?

The facts

Flowers are made of four main parts: the sepals, petals, stamens and carpels. The arrangement of the basic parts also varies from flower to flower. Fig 2.13 below shows a generalised parts of a flower.

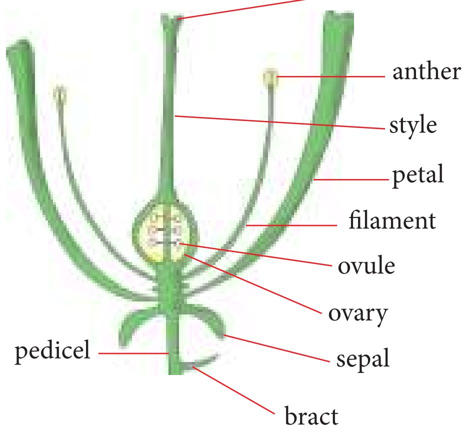


Fig. 2.13: Parts of a flower

Structure and function of parts of an insect pollinated flower

A **hibiscus** flower is attached to the stem or branch of the plant by a **flower stalk** or **pedicel**. The top part of the flower stalk is sometimes known as the **receptacle**. It is the point from which the *hibiscus* flower parts arise. There are four flower parts each arranged in a circle around a point.

The outermost part is made up of an **epicalyx**, followed by **calyx**, then **corolla**. Finally at the centre is the **gynoecium** (female parts) which is made up of **carpels** and **androecium** (male parts).

In the *hibiscus,* the stamens are fused to make a hollow tube with free anthers towards its end while the styles are fused with free sticky stigmas towards its tip. The structure and functions of the above-named parts of a *hibiscus* flower are the same for most insect pollinated flowers. We will now study each part of the flower in order to see how it relates to its function.

a) Calyx

The calyx is made up of **sepals** which are leaf-like structures. They may be free and separate or fused to form a tube-like structure as in the *Hibiscus* flower. They protect the inner parts of the flower before it opens when it is still in bud form from desiccation or drying up. It also protect the inner parts from being attacked by aphids. They are usually green in colour but are brightly coloured in some flowers.

b) Corolla

The corolla is made up of **petals**. They are found next to the sepals. They are large and colourful in insect pollinated flowers. They are either fused to form a tube or are free and separate. They are important because they attract insects for pollination. They also protect the inner parts of the flower from mechanical damage.

c) Stamens

The stamens form the male part of the flower known as the **androecium**. One stamen consists of four pollen-containing sacs which are fused together to form an anther.

Fig. 2.14: Cross section through anthers to show pollen sacs

The anther is attached onto a stalk known as a **filament**. The anther and the filaments form the **stamen**. In the *Hibiscus* flower, there are very many stamens and their filaments are joined to form a hollow tube. Fig. 2.15 shows the parts of the stamen.

Fig. 2.15: Anthers, filaments and tube of fused/joined filaments in Hibiscus

Pollen grains are formed inside the anthers. The number, arrangement, shape and attachment of stamens to the flowers vary from one plant to another.

Some flowers are called **staminate** flowers because they have only stamens and no carpels along with the other parts of the flower. The main function of the stamens is to produce pollen grains, which contain male gametes.

Pollen grains are formed in the pollen sac. The sacs contain cells called pollen mother cells. They undergo meiosis to form 4 haploid cells called **tetrads.** The tetrads mature to form pollen grains. The nucleus is called the **generative nucleus**. It forms the two male nuclei involved in fertilisation of ovules. The second nucleus is called **tube nucleus.** It is involved in formation of pollen tube during pollination.

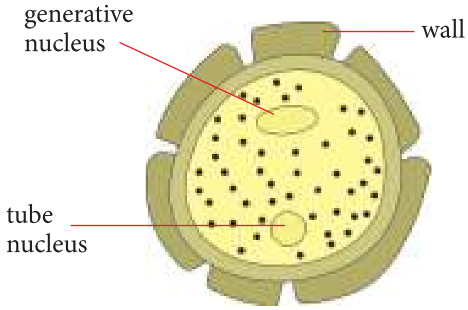


Fig 2.16: Internal structure of a pollen grain

Once the pollen grains in the anthers are fully formed, the anther is described as being mature. The cells of the outer layer of the wall of the pollen sac dry out. This creates tension which causes the anther to split at the line of weakness present on each side of the anther as shown in the diagram below.

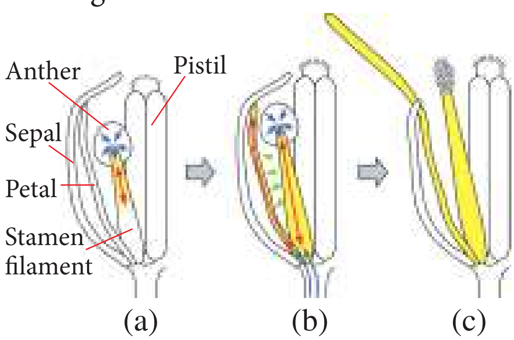


Fig 2.17: Dehiscing anther releasing pollen

(d) Carpels (Pistil)

A flower can have one or more carpels also referred to as the **gynoecium** which is the female part of the flower. Each carpel consists of a stigma, a style and an ovary. It is also referred to as the ***pistil.***

The ovary has a hollow space or cavity which contains one or several ovules. The reproductive cell is an egg cell and it develops inside the ovule. The ovule contains a structure called an **embryo sac** which contains the egg cell.

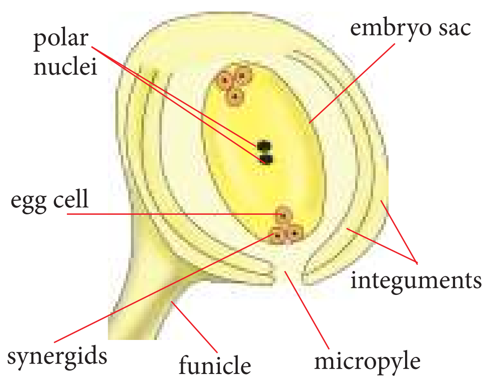


Fig 2.18: Internal structure of the ovule

The ovule is joined to the ovary by a stalk called **funicle** on a tissue called the placenta. The ovule consists of a large cell called **embryo sac** mother cell. The cell divides by meiosis to form 4 haploid cells.

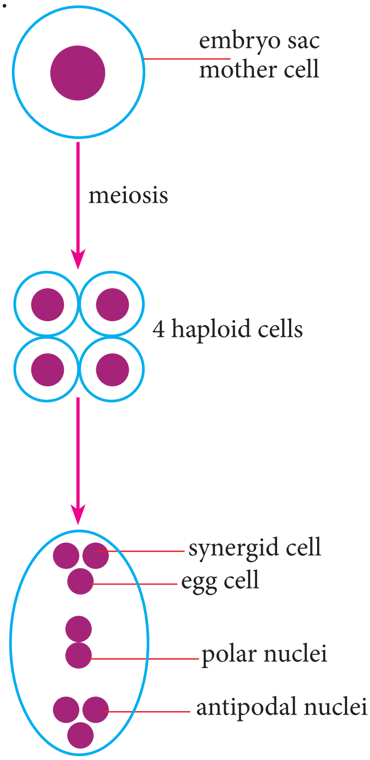


Fig. 2.19: Embryo sac mother cell dividing to 4 haploid cells

One cell forms embryo sac and the other cell disintegrates. The nucleus of the embryo sac divides to 8 nuclei. Two nuclei form polar nuclei at the centre. One cell towards the micropyle forms the egg cell. Two nuclei near the egg cell are called **synergids.** The other three nuclei to the far end form the antipodal cells.

The stigma receives the pollen grains during pollination. The style holds up the stigma in such a way that it can receive pollen. The main function of the carpels is to produce female reproductive cells or gametes. In the *hibiscus* flower, there are five carpels. The ovaries and styles of the five carpels are fused (joined) but the stigmas remain separate.

Did you know?

The joined styles shown in the following diagram are located inside the tube of fused filaments seen earlier.

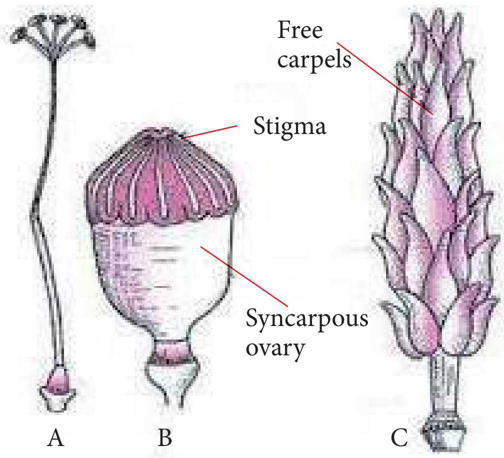


Fig. 2.20: Fused styles (without filaments and anthers)

The *hibiscus* flower also has a scent. This scent attracts insects to it. Some insect pollinated flowers produce a sugary liquid called **nectar**. It is produced by glands called nectaries located at the lower end of the petals.

Insect pollinated flowers also produce pollen grains that are large and have rough surfaces or spiky structures that readily adhere onto the bodies of insects. The anthers in the flower are positioned in such a way that the insects are likely to brush against them as they move around the flower. The stigma too is located inside the flower in a position that the insect is likely to brush against it as it enters the flower. Such stigmas are usually flat or lobed. They are also sticky in order to trap pollen.

Check your progress 2.4

1. The female and male reproductive structures of a flower are the:
   A. Petals and sepals
   B. Receptacle and epicalyx
   C. Pistil and stamen
   D. Calyx and corolla
2. Identify the odd one out.

   Ovary, anther, ovule and pistil
3. The following describes the structure of a flower. Which one does not apply to a wind pollinated flower?
   A. Anthers dangle out of the flower
   B. Brightly coloured
   C. Large quantities of pollen produced
   D. Stigma are large and feathery
4. Draw a flower and on it label the following:
   (a) Part of the stamen that supports the anther

(b) Part of the pistil that is adapted to receive pollen grains

(c) The part that protects the inner parts of the flower

5. What are synergids?

2.4 Pollination

Activity 2.7: Investigating flower structures of wind and insect pollinated flowers

Work as a group

Materials

- Flowers collected in Activity 2.6
- Hand lens

Procedure

1. Collect wind pollinated flowers such as grass flowers and insect pollinated flowers such as *hibiscus*.
2. Using a hand lens, observe the anthers and stigma of the two flowers.
3. Study the flowers that you have collected.
   - Note how the anthers and stigma of the two flowers are held by the filaments and style respectively.
4. Study the petals of the two flowers.
5. Group the flowers into those that were visited by insects and those that were not.
   - Do you notice any similarities in colour or scent among the two groups of flowers (those visited by insects and those not visited by insects)?
6. Make a list of the characteristics of flowers visited by insects and do the same for those not visited by insects.
7. Fill out the following table to show the differences between the two flowers.

Table 2.1: Features of flowers

Features of a flower	Insect pollinated	Wind pollinated
Anther		
Erect stigma		
Petals		
Nectaries		
Quantity of pollen grains		
Nature of pollen grains		
Scent		
Nature of stigma		

8. Compare your results with those of other groups.
9. Present your work to the rest of the class.

Caution: Some flowers are visited by insects that sting such as bees. Be careful as some insects can be dangerous when disturbed.

Study questions

1. Why do insects visit some flowers and leave other flowers?
2. What role do insects play in sexual reproduction in flowering plants?
3. List some of the characteristics of flowers most commonly visited by insects. Make a second list of characteristics of those flowers not commonly visited by insects.

The facts

The structure of some flowers is modified to encourage insects to visit the flowers and lead to pollination. Other flowers have features that enable wind pollination.

Wind pollinated flowers

- Flowers that are wind pollinated usually occur in groups called **inflorescences** on the plant. They produce pollen grains that are very small with smooth surfaces so that they do not clump together.
- They have light weight to be lifted easily by air currents from the anthers of one flower to the stigma of another easily.
- They have features that ensure pollination takes place. For their pollen grains to be readily dislodged from the anthers and be airborne, the flowers have well exposed stamens with anthers dangling out of the flower.
- The stigmas of such flowers are large and feathery creating a net to ensure that the pollen in air is trapped and lands on the stigma.
- Large quantities of pollen are produced. This is to ensure that there are increased chances of some of it landing on the stigmas because the wind also blows most of it away and it is lost.
- They have groups of two or three flowers which form spikelets. The spikelets are borne on a common stalk forming an *inflorescence* as shown in Fig. 2.21.

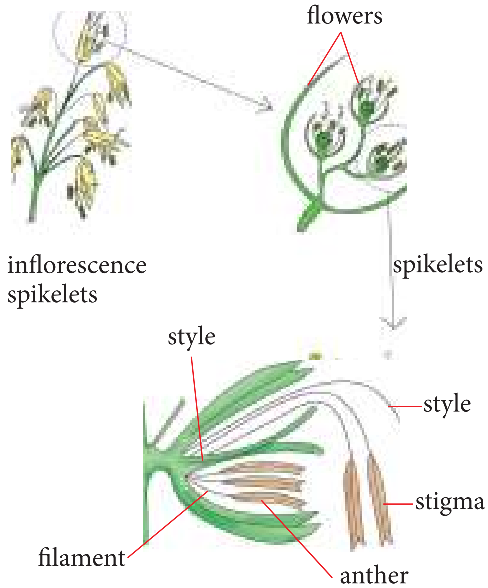


Fig 2.21: Wind pollinated flower

Activity 2.8: Research Activity

Work as an individual

1. Using textbooks and the internet, research on the following:
   (a) Meaning of the term pollination.
   (b) Differences between self-pollination and cross pollination.
   (c) Compare the features of insect and wind pollinated flowers.
2. Compare your findings with the rest of the class.

The facts

Male gametes are formed inside the anthers in pollen grains while female gametes are formed in the ovary inside the ovules. Therefore, reproduction cannot occur unless the gametes meet. Pollen is transferred from the anthers to the sticky stigma in a process called **pollination.**

Pollination is important because the male gametes are found inside the pollen grains and require to be exposed or brought closer to the female gametes. There are two types of pollination.

- Self-pollination
- Cross pollination

Self-pollination is when pollen from the anther of the same plant arrives at the stigma of the flower. There are two types of self-pollination: that is autogamy and geitonogamy. In **autogamy,** pollen is transferred to the stigma of the same flower. Some plants have mechanisms that ensure autogamy, such as flowers that do not open or stamens that move to come into contact with the stigma. In geitonogamy, pollen is transferred from the anther of one flower to the stigma of another flower on the same flowering plant. Few plants self-pollinate without the aid of pollen vectors (such as wind or insects). The mechanism is seen most often in some legumes such as peanuts**.** Most of the self-pollinating plants have small, relatively inconspicuous flowers that shed pollen directly onto the stigma, sometimes even before the bud opens. Self-pollinated plants expend less energy in the production of pollinator attractants and can grow in areas where the kinds of insects or other animals that might visit them are absent or very scarce—as in the Arctic or at high elevations.

Advantages of self-pollination

- Self-pollination can be an advantage when the number of flowers is small or widely spaced. During self-pollination, the pollen grains are not transmitted from one flower to another. As a result, the wastage of pollen is less.
- It also does not depend on any external carrier. The plant that develops in that way of pollination cannot make changes in their characters and so the features of a species can be maintained.

Disadvantages of self-pollination

The disadvantages of self-pollination come from a lack of variation that allows no adaptation to the changing environment or potential pathogen attack.

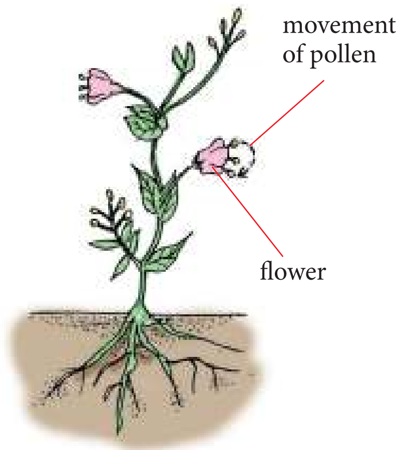


Fig 2.22: Self –pollination

When the pollen is transferred from the anthers of a flower from one plant to the stigma of a flower on another plant, this is called **cross pollination.** The two plants should be of the same species.

Characteristics of cross pollinated plants

- Flowers are small and inconspicuous.
- Non-essential parts are either absent or reduced.
- The flowers are colourless, odourless and nectarless.
- In case of unisexual flowers, the male flowers are more abundant. In bisexual flowers, the stamens are generally numerous.
- Flowers are produced above the foliage, before the appearance of new foliage or placed in hanging position.
- Pollen grains are light, small and winged or dusty. They can be blown by wind to distances of up to 1300 km.
- Pollen grains are dry, smooth, nonstick and unwettable.
- Stigma is hairy, large, feathery or branched to catch the wind-borne pollen grains.
- Pollen grains are produced in very large number. Consequently, the pollen grains spread over large tracts so that even isolated plants get pollinated.

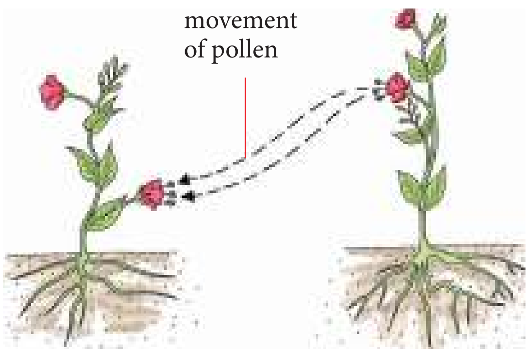


Fig 2.23: Cross pollination

Advantages of cross pollination

- A number of plants are self-sterile, that is, the pollen grains cannot complete growth on the stigma of the same flower. Cross pollination therefore allows complete growth on stigma.
- Cross pollination introduces genetic combinations and hence variations in the progeny. New and more useful varieties can be produced through cross pollination.

- Cross pollination increases the adaptability of the offspring towards changes in the environment.
- It makes the organisms better fitted in the struggle for existence. The plants produced through cross pollination are more resistant to diseases.
- The seeds produced are usually larger and the offspring have some characteristics that are better than the parents due to the phenomenon of hybrid vigour.
- The defective characters of the race are eliminated and replaced by better characters.
- Yield never falls below an average minimum.

Disadvantages

- It is highly wasteful because plants have to produce a larger number of pollen grains and other accessory structures in order to suit the various pollinating agencies. Therefore, less economical.
- A factor of chance is always involved in cross pollination.
- Some undesirable characters may be produced during cross pollination.
- The very good characters of the parent plant are likely to be spoiled.

Agents of pollination

Pollen requires an agent to carry it to ensure its transfer from anther to stigma. An **agent of pollination** can therefore be defined as the means by which the pollen grains can be transferred from anthers to stigma. Examples of these means are animals, for example insects, spiders, human beings, humming birds, wind and water.

Activity 2.9: To investigate insects and wind pollinated flowers.

Work as a group

Materials

- Flower of plants such as rose
- Maize
- Grass
- Hibiscus

Procedure

1. Study each of the flowers listed above.
2. Design a table where you are going to record the features that you have observed in each of the flowers.
3. Use the following guidelines.
   a) Flowers scented and have nectar.
   b) Flowers large, conspicuous, with brightly coloured petals.
   c) Stigma small and sticky.
   d) Stigma large and feathery.
   e) Pollen grains small, light and smooth.
   f) Flowers not scented and lack nectar.
   g) Flowers small and inconspicuous.

The facts

Insects like ants, bees, wasps, termites, moths and butterflies are the most common animals that pollinate flowers. Insects are attracted to flowers that are scented and brightly coloured. Insects also visit flowers to look for pollen and nectar which is food to them.

As the insects move in and out of the flower some of the pollen previously stuck on their bodies from other flowers, stick onto the sticky stigma in the flowers. This way the insect acts as an agent of pollination. Insect pollinated flowers are said to be **entophilous.**

Wind is moving air. When the wind blows it readily dislodges pollen which is loosely held on the anther. Such pollen is carried by the wind to stigmas that have feathery net-like structures. They readily trap the pollen. Wind pollinated flowers are said to be **anemophilous.**

Table 2.2: Characteristics of wind pollinated and insect pollinated flowers

Insect pollinated	Wind pollinated
Flowers have petals that are large and brightly coloured. Very conspicuous.	Flowers are small with green bracts. Not very conspicuous.
Have nectaries with nectar guides to direct the insects to the nectaries.	No nectar and nectaries.
Are scented.	Not scented.
Small rigid sticky stigmas located inside the flower.	Stigma often feathery and large. Mostly hanging outside the flower.
Pollen grains have rough crispy surface.	Pollen grains are small, light-weight, have smooth surfaces and are produced in large amounts.
Anthers are small, attached firmly to the filaments and located inside the flowers and positioned where the insects can brush against them.	Anthers are large and loosely attached to the filaments. They are on filaments that dangle out of the flower. They shake readily when the wind blows.

Activity 2.10: Research Activity

Work as an individual

1. Carry out a research on the features and mechanisms that hinder self pollination and self-fertilisation.
2. Write a report on your findings and compare with other class members.

Check your progress 2.5

1. What is pollination? State two types of pollination.
2. Why do you think farmers who grow cereals such as wheat, barley and rice ensure that the plants grow close to each other?
3. What will be the effect on flower pollination on the yield of some crop plants if pollinating insects are accidentally killed by insecticides?
4. What feature of the stigma of an insect pollinated flower enables the pollen grain to adhere?
5. What are the advantages of self pollination?

2.5 Fertilisation and seed formation

Activity 2.11: To familiarise with the process of fertilisation and seed formation

Work in pairs

Requirements

- Computer animation
- Charts and diagrams

Procedure

1. Observe the computer animations or charts and diagrams.
    - Can you trace the path of the gametes during fertilisation?
2. Make a drawing of the path taken by the gametes.
3. Compare your work with others.

Study questions

(i) How does fertilisation occur in a flower?

(ii) What structures are involved during fertilisation?

(iii) How does a seed develop after fertilisation?

The facts

When the pollen grain lands onto the sticky stigma, it germinates. A pollen tube emerges from the grain and quickly grows down the style to the ovary.

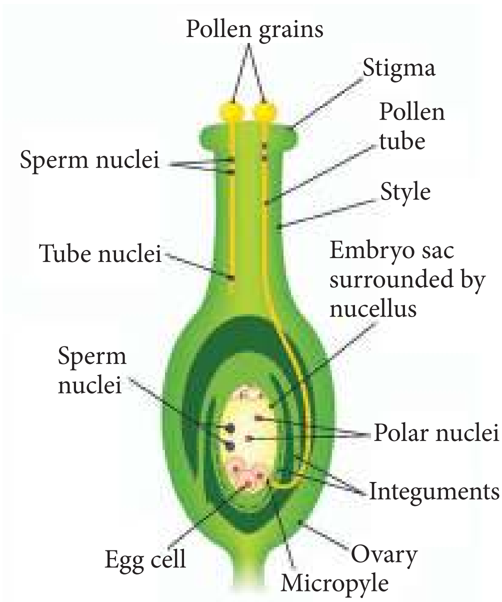


Fig 2.24: Vertical section through a pistil just before fertilisation

The pollen grain has two nuclei in it: the generative nucleus and the pollen tube nucleus. The generative nucleus is immediately behind the pollen tube nucleus. The generative nucleus divides to form the male gametes (or nuclei). The tube nucleus is located at the tip of the tube and it directs and controls the growth of the tube to the ovary. As the tube continues growing downwards, the generative nucleus divides by mitosis. It forms two male nuclei which represent the male gametes.

The pollen tube then grows through the ovary wall and reaches the ovule and enters it through the **micropyle**. At this point, the role of the tube nucleus is over and it degenerates (breaks up). The tip of the pollen tube then bursts open to release the two male nuclei.

The two male nuclei enter the part of the ovule known as the embryo sac. One male nucleus fuses with the nucleus in the egg to form a fertilised egg cell or zygote. The other male nucleus fuses with the two polar nuclei to form a triploid nucleus (i.e. a nucleus with three sets of chromosomes) known as the primary endosperm nucleus. This is known as **double fertilisation**.

In some ovaries, there are several ovules, for example, the ovary of a bean flower. In such a case, several pollen grains are responsible for the fertilisation of the ovules in that ovary.

In some plants, fruit formation takes place without fertilisation. This process is called **parthenocarpy.** Example is in bananas, pineapples and grapes.

Seed formation

Activity 2.12: Examining embryo of seeds

Work in pairs

Materials

- Bean and pea seeds soaked in water.
- Forceps

Design an experiment using the materials provided.

Study questions

(i) What is the shape of a bean seed and pee a seed?

(ii) How do we call the notch at the bean seed?

(iii) Make a drawing of bean seed and name its parts.

After fertilisation of the flower, several changes take place in it. The zygote formed undergoes mitotic division to form an embryo which comprises of three parts: the plumule, radicle and cotyledons.

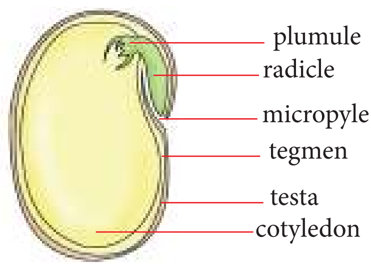


Fig 2.25: Parts of a seed

A seed that has one cotyledon is known as a **monocotyledonous** seed. Examples include maize and wheat. A seed that has two cotyledons is known as a **dicotyledonous** seed, for example beans and peas. The cotyledon or endosperm stores food substances for the growth and development of the embryo during germination.

The part of the ovule that were the integuments develop into **seed coats**. The inner integument becomes the **tegmen** and the outer integument forms the **testa**. These form protective layers of the seed.

What was originally the micropyle remains as a tiny pore or hole through which oxygen and water enter the seed when it germinates. The seed also loses most of its water. This reduction is from 90% of the total seed mass to about 10%. This reduces the chemical or metabolic activities that occur in the cell. The seed can then enter a period of reduced growth and development called **seed dormancy**. In this condition, the seed can withstand adverse conditions.

Check your progress 2.6

1. You are provided with the following: mango, castor, rice and pea. Which ones are monocots and dicots?
2. Outline the stages in seed formation.
3. Draw and label parts of a seed.

2.6 Fruits, seed dispersal and germination

The fertilised ovary develops into a fruit. A fruit can also be described as a mature ovary. Its main function is to protect the inner seed or seeds and to assist in their dispersal. In the process, the ovary develops into a fruit. The ovary wall becomes the fruit wall or pericarp. The pericarp varies in structure from one fruit to another. It may be thick or it may be thin. It has three main functions.

- Its main role is to protect the seed and therefore the embryo.
- It also acts as a storage of food.
- It is important in the dispersal of seeds.

In ovaries that have matured into fleshy fruits, three distinct regions in the pericarp can be noted. The outer part or skin is called the **epicarp**. The middle part is the **mesocarp** and the inner part which surrounds the seeds is the **endocarp**.

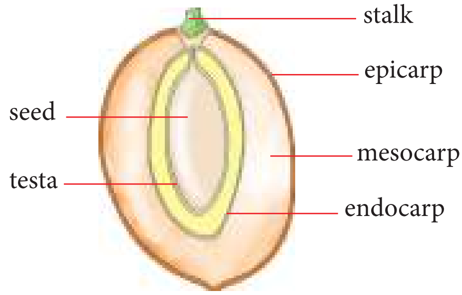


Fig 2.26: A section through a fruit showing various parts of a fruit

There is a great diversity of fruits. This is because of the great variation of flowers that exist. The type of flower influences the type of fruit that will be formed. For example, if the flower was an *inflorescence* i.e. had several flowers in a cluster, then multiple fruits form. Fruits can be classified into two main groups; **dry fruits** and **succulent fruits**.

Dry fruits are fruits whose pericarp dries up enclosing the seeds. Examples include legumes, maize grains and nuts. Succulent fruits include mangoes, berries, apples and oranges.

Dispersal involves the scattering of seeds and fruits away from the parent plant. Many different adaptations have arisen to enable efficient dispersal. This ensures that plants do not grow very close together to avoid competition for water, minerals and sunlight. The mode of dispersal of the seed or fruit depends on the agents of dispersal which are: animal, wind and water.

Fruit and seed dispersal

Suppose that most of the fruits dropped immediately beneath the parent plant. This would mean that the seeds in the plant would eventually get exposed and eventually germinate around the parent plant.

This would lead to overcrowding. All the plants would compete for light, space, soil nutrients and water. This means that they would not grow to become healthy and strong enough to survive and carry out the cycle of reproduction once more. This can endanger the survival of the plant species.

Activity 2.13: To describe the mechanism of dispersion of seeds and fruits

Work as a group

Materials

- Hand lens
- Scalpel
- Variety of fruits and seeds

Procedure

1. Using the materials provided above, design an experiment that can be used to classify fruits into different categories. Present your results in form of a flow diagram.
2. Which fruits and seeds are dispersed by:
   a) wind?
   b) water?
   c) sensor mechanism?
   d) animals?
3. How are the fruits adapted to dispersal by the methods above?

The facts

After fertilisation, the ovule develops into a seed and the ovary into a fruit. The process of reproduction would not be complete if the seed did not reach favourable ground in order for it to germinate and grow into a new plant.

Seeds should be able to reach new and suitable ground where the parent plant is not growing and where few such seeds are also growing. This means that the seeds should leave the parent plant either on their own or in the fruits. The process by which seeds and fruits are spread from the parent plant is known as **dispersal.**

Seed dispersal is important because it ensures that too many plants do not grow and overcrowd around the parent plant. It also ensures that seeds reach new and suitable habitats where there is no competition for resources.

There are several methods of fruit and seed dispersal. They range from physical means, for example, when they are dispersed by wind or water or by biological means, for example, when dispersal by animals like birds, monkeys, humans among others.

There are some plants that have mechanisms that can forcefully eject their seeds from the fruit to some distance away from the plants i.e. self dispersal.

Dispersal by wind

Seeds or fruits that are dispersed by wind are usually small or light in weight. They may or may not also have wing-like or hair-like structures that keep them air borne.

1. Seeds and fruits with wing-like structures

Some seeds have part of their structure extended to form wing-like structures which are flat, broad and papery. These structures create a large surface area against which the wind can blow, pushing them far away from its parents. Common examples are the *Jacaranda* seeds, *Tecoma* and *Spathodea* seeds.

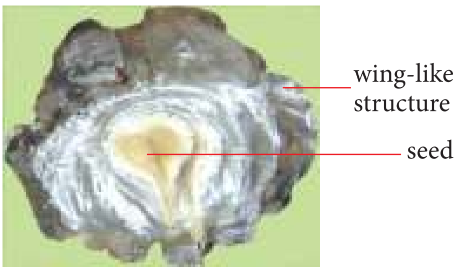


Fig 2.27: Jacaranda seed

2. Fruits and seeds with hair-like structures

Some fruits and seeds have many hair-like structures that project from their surfaces. These increase the surface area of the fruit or seed. Because of this, they can be blown by the wind over large distances and as they fall to the ground slowly, they look like parachutes. Examples are *Sonchus,* which have a pappus of hairs on their fruit, and cotton seeds, which have hairs that grow out of the seed coat.

Fig 2.28: Seeds with hair-like structures

3. Fruits that disperse seeds by the censor mechanism

Some ovaries form dry capsules which open partially at the top to expose the seeds. The capsules are at the end of long stalks. Some seeds are shaken out and dispersed. The wind aids the dispersal of the seeds which are usually very tiny.

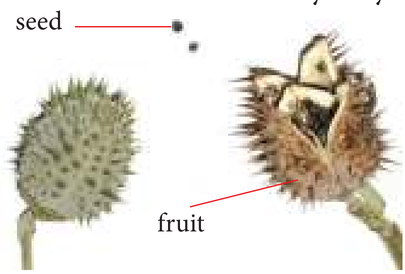


Fig 2.29: Seeds dispersed by censor mechanism

Animal dispersal

1. Some fruits have hooks on their surfaces

These hooks attach on the fur of mammals or people's clothes as they pass. They are moved away from the parent plant by the animal and they later fall off onto the ground or are removed by the animal as it cleans itself. Such seeds eventually germinate and grow into new plants away from the parent plant. Example is a black jack fruit.

2. Other fruits have pericarps that are succulent and edible

This makes them attractive to animals as a source of food. Birds and mammals like monkeys eat the fruits.

Some seeds are swallowed, but because they have seed coats that are resistant to digestion by enzymes, they pass out of the digestive tract with the faeces later.

Once they reach the ground away from the parent, they germinate into new plants if conditions are favourable. Examples are passion and guava seeds. Some of the seeds are in fruits which are edible. They are picked by humans as food. Once the fruit is eaten, the seeds are disposed off to areas away from the parent plant. They later germinate and grow into new plants. In this way, human beings are agents of seed dispersal.

Water dispersal

Water dispersal is the method in which some fruits and seeds are carried away from where the parent plant is growing to new ground by water. This happens when the parent plant is growing near a river, lake or ocean. The seeds or fruits drop off from the plant into the water and water currents sweep it away to another place. Some examples of fruits like the coconut have structures that suit them to water dispersal. The coconut, being a drupe, has a fibrous mesocarp which contains many air spaces.

The air spaces make the fruit light, enabling it to float in water. The pericarp is water proof to enable it float without soaking in water.

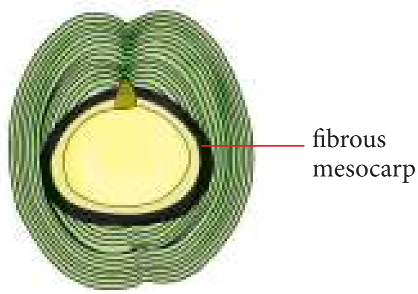


Fig 2.30: Coconut fruit

Self dispersal

Self dispersal is the method by which mechanisms in the fruit eject the seeds. Flowers like those of the bean plant form pods, which dry and shrivel, the pericarp shrinks and some tension is set up in the fruit wall. Along two sides of the pod are two lines or seams of weakness, the pod splits along these lines. Each half twists suddenly and projects the seeds with some force away from the parent plant. This method is sometimes referred to as the explosive method. It occurs in plants such as legumes, for example, squirting cucumber and wall flower plant.

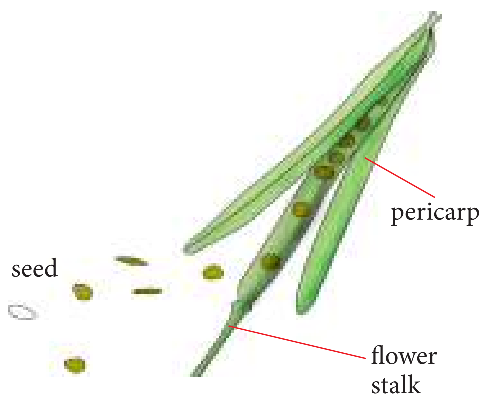


Fig 2.31: Wall flower fruit

Importance of seed and fruit dispersal

Dispersal of fruits and seeds is important for the survival of any plant species since:

- Reduced overcrowding of seedlings which would grow around the parent plant resulting to competition for resources.
- Seeds may be dispersed to new areas with more suitable conditions than where the parent plants are growing.

Germination

Germination is the development of a seed into a seedling. After seed formation, the seed undergoes a period of dormancy. Once this dormancy is broken and necessary factors for germination are provided, the physiological activities in the seed are activated, leading to germination. Only a viable seed can germinate. This is a seed in which the cells remained alive during dormancy.

For the seed to germinate, it needs water, oxygen and a suitable temperature. Before germination, many seeds go through a period of dormancy that is accompanied by very low metabolic activities such that growth does not occur. There are two types of germination, that is **hypogeal** and **epigeal**.

Conditions necessary for germination

1. Water

For germination to take place, water enters the seed through the micropyle in a process known as **imbibition.** This causes the seed to swell, and the testa to soften and eventually break. Enzymes in the seed become activated. They break down food stored in the cotyledon and endosperm into simple soluble substances in a process known as **hydrolysis.** Stored starch is broken down to glucose, stored proteins into amino acids and stored lipids into fatty acids and glycerol.

These soluble food substances are transported by the water from the storage parts of the seed to the regions of growth in the plumule and radicle. As a result of the assimilation of these food substances, the plumule and radicle increase in size and they grow out of the seed. The cotyledons and endosperm shrink due to the depletion of the stored food.

Activity 2.14: To investigate the necessity of water in germination

Work as a group

Materials

- Seeds
- Petri dishes
- Water
- Cotton wool

Design an experiment using the set of materials provided above to demonstrate that water is a necessity during germination.

2. Oxygen

Oxygen is necessary in germination for the aerobic respiration which provides energy for the growth and development of the seed into a seedling.

Activity 2.15: To investigate the necessity of oxygen in germination

Work as a group

Materials

- Soaked seeds
- Cotton wool
- Flat-bottomed flasks
- Cork
- Water
- Pyrogallic acid and sodium hydroxide
- Hooked wire

You have been provided with the materials above. Using a well labelled diagram, design an experiment that can be used to investigate the necessity of oxygen in germinating seed. Highlight the steps that you will follow when conducting this experiment.

3. Warmth

Warmth provides optimum temperature for maximum enzyme activity.

Activity 2.16: To demonstrate the significance of warmth in germination

Work as a group

Materials

- Petri dishes
- Incubator
- Refrigerator
- Seeds
- Cotton wool
- Thermometer

In groups of four, use the materials above to carry out an experiment aimed at investigating the significance of warmth in germination.

Study questions

1. What observations did you record after the 6 days?
2. Discuss your observations making relevant deductions.

Internal factors that affect germination

1. Enzymes

Enzymes break down food reserves in the cotyledons or endosperm into soluble form. For example, protease breaks down proteins into amino acids.

2. Hormones

Hormones such as auxins act as growth stimulators.

3. Viability

Viability refers to the ability of a seed to germinate. Only alive and healthy seeds with mature embryo germinate. Seeds that have been stored for a very long time may lose their viability.

Epigeal germination

This is a type of seed germination in which the cotyledon emerges above the ground. It is caused by the elongation of the hypocotyls. The hypocotyls elongates as an arch or a hook which pushes upward through the soil. It pulls the cotyledon that encloses the plumule in between them. The hypocotyl straightens, then cotyledons open and turn green. They start to photosynthesis providing food for the developing seedlings for 1-2 days.

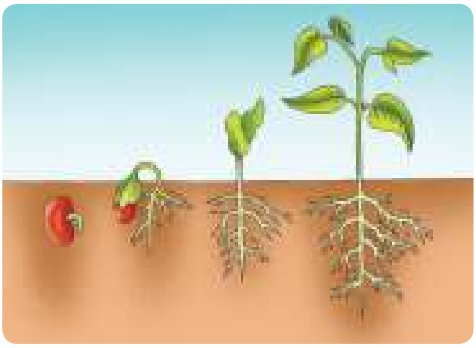


Fig 2.32: Epigeal germination

Hypogeal germination

This is a type of germination in which the cotyledon is left under the ground as the seed germinates. It is caused by the elongation of the epicotyls. The epicotyls elongates straight up with the plumule protected by the sheath known as coleoptiles. The coleoptiles protects the delicate plumule as it penetrates through the soil.

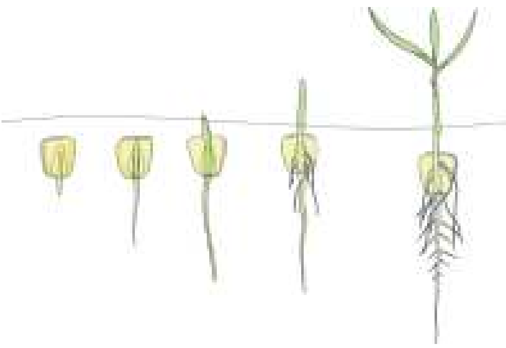


Fig 2.33: Hypogeal germination

Check your progress 2.7

1. What is germination?
2. State the role played by water during germination?
3. Which of the following statements best describes dispersal?
   A. A seed growing into a new plant.
   B. A seed starting to sprout.
   C. The scattering of seeds to other places away from the parent plant.
   D. A seed starting to grow roots.
4. What types of seeds are carried by wind?
   A. Seeds in pods.
   B. Seeds with hairy parachute-like structures.
   C. Seeds with holes.
   D. Seeds with lines of weakness.
5. Not all seeds fall under the parent plant; others are dispersed far away. What is the importance of this?
6. Seed dormancy is important. Explain.
7. What is the role of each of the following in germination?
   (a) Cotyledons and endosperm
   (b) Enzymes

2.7 Seed dormancy

Dormancy refers to the temporary inhibition of growth of an organism or part of it. During seed dormancy, the metabolic activities are usually very slow but sufficient to keep the cells alive. Some seeds, for example lettuce, will not germinate immediately they are shed even if they are provided with suitable conditions.

Importance of seed dormancy

Seeds can survive for long periods of time without depleting their food reserves. Dormancy therefore enables an organism (a seed in this case) to survive adverse environmental conditions such as drought, extreme temperatures and shortage of food.

Causes of seed dormancy

(a) Freezing of seeds.
(b) Embryo may not be fully developed.
(c) Impermeable seed coat to air and water.
(d) Presence of chemical inhibitors.
(e) Lack of oxygen.
(f) Lack of moisture (water).

Ways of breaking seed dormancy

(a) Provide water.
(b) Ensure the seed embryo is mature.
(c) Ensure growth hormones such as gibberellins are present.
(d) Provide air (oxygen).
(e) Inactivate the germination inhibitors.
(f) Provide suitable temperature.
(g) Burn gently some seeds such as Jacaranda which have a hard testa to burst open the seed coat.

Check your progress 2.8

1. Define the term seed dormancy.
2. State three causes of seed dormancy.
3. Mention any two ways of breaking seed dormancy.

2.8 Reproduction

Sexual reproduction involves fusion of gametes from two individual organisms; **male** and **female** referred to as **parents**. Each individual organism produces a reproductive cell known as a **gamete**. The nucleus from the male gamete fuses with the nucleus from the female gamete to form a **zygote** in a process called **fertilisation**.

Organisms that exhibit sexual reproduction have organs (gonads) that are specialised for the formation of gametes. Inside these gonads are specialised cells that can divide to form new gametes. They can do this by undergoing a kind of cell division called **meiosis**. This takes place in higher organisms.

The process of meiosis produces unique reproductive cells called **gametes**, which have half the number of chromosomes as the parent cell. During fertilisation, the fusion of haploid gametes from two individuals restores the diploid condition. Gametes are haploid (containing only one set of chromosomes) while the zygote is diploid (containing two sets of chromosomes).

Thus, sexually-reproducing organisms alternate between haploid and diploid stages.

In sexual reproduction, two individuals produce offspring that have genetic characteristics from both parents. Sexual reproduction introduces new gene combinations in a population through genetic recombination.

Activity 2.17: To examine sexual reproduction in Mucor

Work as a group

Materials

- Microscopes
- Dropper or pipette
- Slides
- A mould culture
- Forceps

Procedure

1. Using forceps, pick some hyphae of the *Mucor* from a mould culture.
2. Add water to prevent them from drying.
3. Mount them on a microscope.
4. Observe and identify hyphae that are undergoing conjugation and zygospores in the specimen.

The facts

As mentioned already, *Mucor* can reproduce asexually by the process of spore formation. However, it can also reproduce sexually through the process of **conjugation**. In this process, two separate hyphae growing alongside each other produce short branches. The branches of the two hyphae come into contact with each other and their tips swell. The walls at the point of contact dissolve and the cytoplasm and nucleus in the swollen part is mixed. This results in fertilisation. The two swollen parts fuse to form one part called a **zygospore**. The zygospore develops a tough outer wall; it then breaks off from the two hyphae. It germinates to produce a new hyphae that continues to grow into a new *Mucor*.

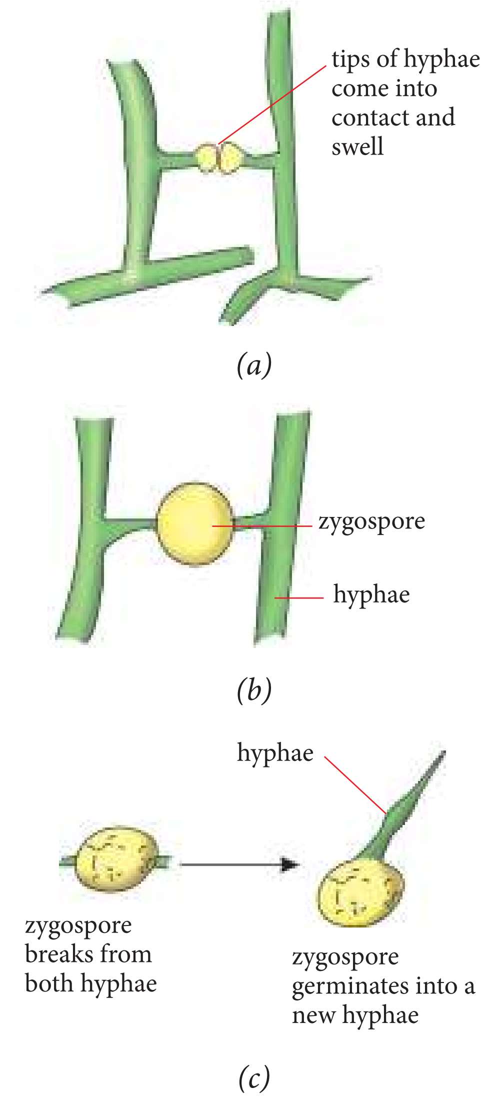


Fig 2.34: Process of sexual reproduction in Mucor

Note: In some organisms, one individual can produce both male and female gametes, for example, some snails and worms.

Activity 2.18: Discussion Activity

1. In groups of four, discuss the advantages and disadvantages of sexual reproduction.
2. Compare your work with the rest of the class.

Advantages of sexual reproduction

1. Offspring produced exhibit variation and improved vigour. The offspring therefore have improved qualities such as higher yields, resistance to diseases and can withstand environmental changes.
2. There is diversity of offspring from their parents. The offspring bears traits from each parent.
3. The only way that a species can evolve is through sexual reproduction.
4. With each passing generation the genes become better suited to handle environmental and biological issues that would wipe out creatures that produce in other ways.

Disadvantages of sexual reproduction

1. Reproduction rate is slower than in asexual. This is because it requires two parents. The parents must use energy in order to find, court or identify and copulate with their mate.
2. Genetic recombination may be counter-reproductive. This is because sexual reproduction is less efficient at passing in genes. The favourable gene combination may be broken.
3. Sexual reproduction also requires more time to produce offspring. Animals may take months before they can produce offspring. In plants, it may take years before they bear fruits.
4. Animal offspring require a large amount of parental effort from the day that they are conceived. The mother must carry the baby and give birth. Then the child has to be taken care of until they are grown and independent enough to survive on their own.

Table 2.3: Comparison between sexual and asexual reproduction

Sexual	Asexual
Two parents are involved.	Single parent is involved.
Male and female gametes are produced during gametogenesis.	No gamete is produced.
Diploid zygote is formed after fertilisation.	No zygote formation.
Meiosis is essential for gamete formation.	Mitosis is essential for spore formation.
There is variation in offspring.	Offspring are identical to parents.
It is slow in propagation.	It is rapid in favourable conditions.
Population numbers increase slowly.	Population numbers increase rapidly.

> ### Check your progress 2.9
> 1. Compare asexual reproduction and sexual reproduction.
> 2. Which statement about sexual reproduction is correct?
>   A. Sexual reproduction needs just one parent.
>   B. The offspring are always genetically identical in sexual reproduction.
>   C. The offspring are not identical to the parents in sexual reproduction.
>   D. None of the above
> 3. From the list below, select the ones that reproduce through fusion of gametes.
>
>   *Grass, mushroom, lion, yeast, sugarcane, mould, fern*
> 4. Give examples of plants which reproduce through the following processes.
>   i) Sexual reproduction
>   ii) Asexual reproduction
> 5. What are the disadvantages of sexual reproduction?

2.9 Sexual reproduction in animals

Sexual reproduction in animals involves the production of male and female gametes. Male gametes are called **sperms** and female gametes are called **eggs** or **ova**. The sperms meet and fuse with the eggs in a process known as *fertilisation.* This can take place externally, that is, outside the female's body in external fertilisation, for example in amphibians, or inside the female's body in internal fertilisation like in most mammals.

Reproduction in amphibians (frog)

Amphibians are animals like frogs, toads, newts and salamanders. This group of animals gets its name from the fact that the young ones live in water and gaseous exchange occurs through the gills. The adults live on land and breath through the lungs.

The young ones live in water mainly because fertilisation takes place externally in water. In external fertilisation, sperms and ova meet outside of a female's body and their nuclei fuse to form a zygote.

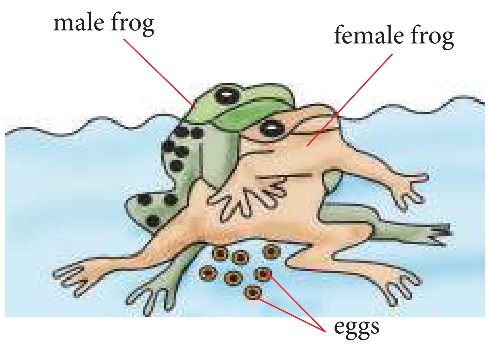


Fig. 2.35: Frogs mating. An example of external fertilisation

Breeding in amphibians usually occurs during the rainy season or in swampy places. When mature, the female frog will be easily distinguished from the male because her body is swollen with mature eggs. The males croak loudly to attract the females. Males and females then pair up. The male mounts the back of the female and clasps tightly. The female may carry the male in that way for a day or two. The pair then gets into the water. The female lays eggs into the water. The male sheds sperms over the eggs as they are laid. When the sperms and eggs meet, their nuclei fuse and fertilisation occurs.

A jelly-like layer in which they are laid in surrounds, coats and attaches them onto a rock or plant.

This layer protects the eggs from injury, bacteria and predators like fish that would eat them, due to its slipperiness.

Despite this, some eggs get lost, some are eaten by fish and some get infected with bacteria and die. Within a day, the eggs hatch into tadpoles and in a month, a fully formed toad or frog develops. Many aquatic animals exhibit external fertilisation because the presence and movement of water makes it possible for the gametes to meet.

The eggs hatch into young ones called **tadpoles** that live in water.

Sexual reproduction in bony fish

In fish, reproduction is sexual with external fertilisation taking place. A female fish with a body swollen with eggs finds a nest and is closely approached by a male. The female lays eggs in a nest and the male immediately sheds sperms on the eggs to fertilise them.

The male keeps guard over the eggs which later hatch into new young fish.

Sexual reproduction in birds

Birds reproduce by means of internal fertilisation.

Birds have courtship behaviour which serves to attract the opposite sex of the same species.

The male bird mounts the female and copulation occurs. Sperms from the male bird are ejaculated directly inside the female's body. Sperms swim up the oviduct and meet the newly formed eggs and fertilisation occurs. The fertilised eggs have albumen and a shell enclosed over them. (Fig. 2.36)

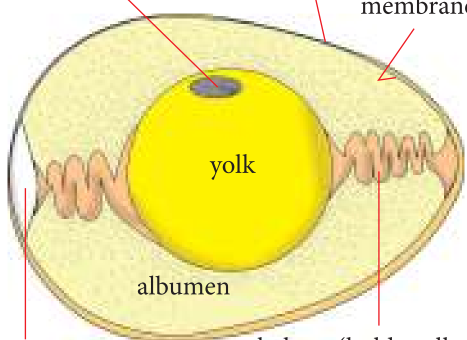


Fig. 2.36: Vertical section through a bird's egg

The bird then lays the eggs in a nest. The fertilised egg moves along the oviduct where the albumen, shell and other substances are added. The shell hardens and the egg is then laid.

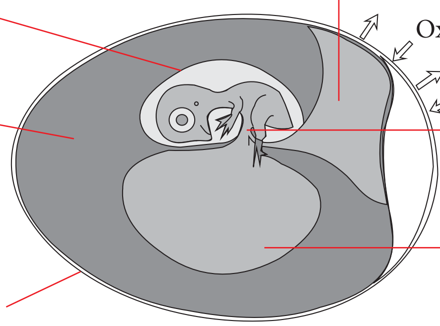


Fig. 2.37: Chicken egg with 10-day-old embryo

The bird then keeps the eggs warm by sitting on them. This process is called **incubation**. During incubation, the germ cell carries out cell division to produce new cells. These cells differentiate to form an embryo.

The embryo is surrounded by a fluid filled sac called amnion. Figure 2.37 below shows a chick embryo at day 10 of development.

In two or three weeks the eggs hatch. A chick breaks the egg shell and emerges from it. The young chicks are called **nestlings** and are fed and kept warm by their parents for some time.

Sexual reproduction in insects

Insects reproduce sexually by internal fertilisation. The insects then lay eggs which hatch into larva that undergo metamorphosis.

Activity 2.19: To observe stages of insect life cycles: The life cycle of a housefly

Work in pairs

Materials

- A piece of fresh meat
- A lid with holes
- A specimen glass bottle

Procedure

1. Put the piece of fresh meat into the bottle and then put it in an open place. Leave it open for 1-2 days to attract houseflies to lay eggs.
2. Examine the colour and size of the laid eggs.
3. Pick the bottle and cover it with the lid that has holes. The holes are for allowing air in and out of the jar.

4. Observe the jar closely each day. Note the number of days the eggs take to hatch into larva (maggot).
5. Examine the maggots and note their features. Observe them each day and note the number of days they take to turn into pupa.
6. Examine the pupa until it emerges into an adult.
7. Record the observations you have made in the life cycle of a housefly.

Check your progress 2.10

1. Briefly describe reproduction in a frog.
2. Distinguish between sexual reproduction in birds and in insects.

2.10 Sexual reproduction in human beings

1. Study the cycle below carefully. What is it about?

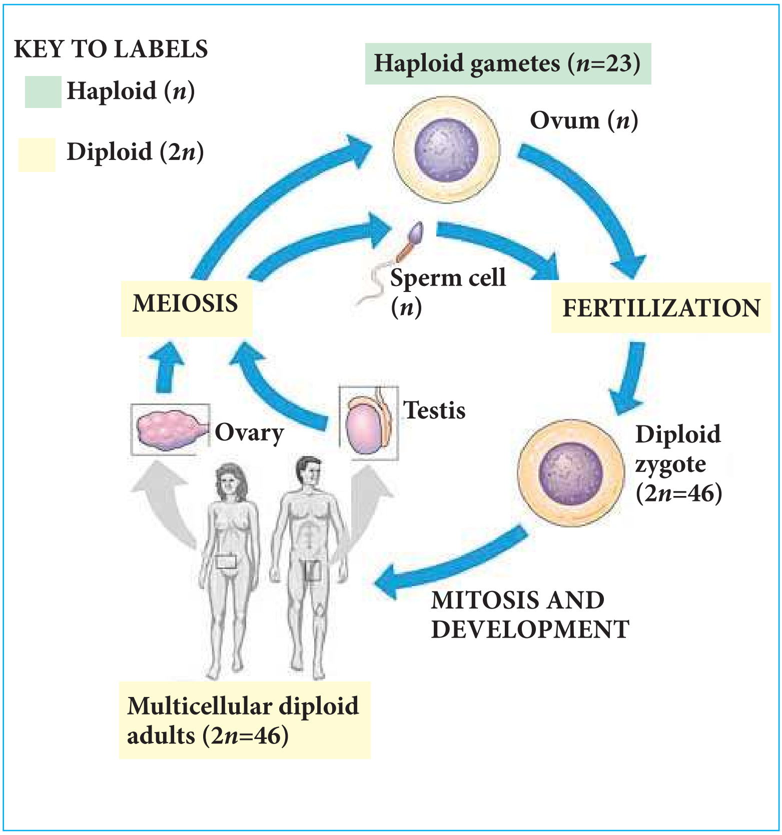


Fig 2.38: Human reproduction cycle

2. Find out what happens:
   a) during fertilisation
   b) cell division and mitosis
   c) Meiosis
3. What does this tell you about how reproduction occurs in human beings?

Introduction

Living organisms do not live forever. There comes a time when living organisms die. In spite of the numerous deaths, life has never ceased from the earth. It is not likely for it to disappear either. One would then ask "what makes it possible for life to continue when organisms are continuously dying?" The answer to this question is that living things have the ability to form new ones. This is known as **reproduction**.

Reproduction is one of the characteristics of living things. In human beings, reproduction involves two different mature individuals: **male** and **female**. The individuals possess reproductive organs **(gonads)** that produce sex cells or **gametes**. The male gamete **(sperm)** and female gamete (**egg** or **ovum**) meet and fuse during **fertilisation** to form a zygote which later develops into a baby.

Male and female reproductive systems

Activity 2.20: Identifying parts of the male and female reproductive system

Work as a group

1. Using charts and computer animations provided:
   - Study the parts of the male and female reproductive systems.
   - Observe photomicrographs of the male and female gametes.
   - Identify the internal structures of the male and female reproductive systems.
2. Discuss the functions of these parts.
   - Compare the adaptive features of the male and female gametes.
3. Present your work in class.

The male reproductive system

The male reproductive system consists of the following main structures: the testes (singular testis), scrotum or scrotal sac, seminiferous tubules, vas deferens (singular vas deferentia), epididymis, urethra, penis, cowper's gland, prostate gland and seminal vesicles.

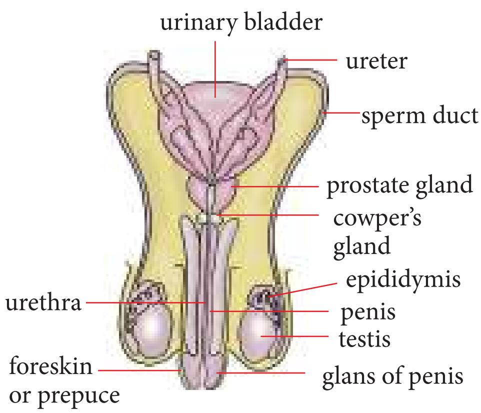


Fig 2.39: The male reproductive system

The male gonads are called **testes** (*singular- testis*). They are two in number. The testes produce sperm cells as well as the male androgen, testosterone. Testosterone is responsible for secondary sexual characteristics in males.

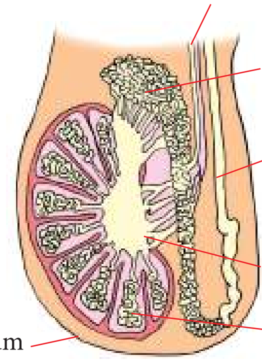


Fig 2.40: Internal structure of the testes

The two testes are located in a sac of skin called the **scrotum** which hangs outside the body wall. The scrotum is suspended immediately beneath the base of the penis. The function of the scrotum is to support and protect the testes. It also ensures that the testes are located at a lower temperature than that of the body. This is because sperms require temperatures slightly lower than that of the body for their production.

Each testis is made up of numerous fine coiled tubes called **seminiferous tubules** where sperm cells are formed. The walls of these tubules have specialised cells that produce sperms or spermatozoa. Other specialised cells located in between the seminiferous tubules, known as interstitial cells, produce and secrete the hormone testosterone. In the seminiferous tubules, cells known as sertoli cells provide nourishment to the developing sperms.

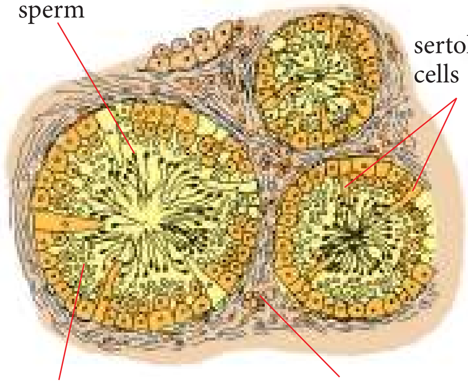


Fig 2.41: Cross-section of seminiferous tubules with sperms

The testes is linked to the epididymis by **vas defferentia**, which are tiny tubes that direct the sperm from the seminiferous tubules to the epididymis. In the **epididymis**, sperm are stored temporarily as they mature. The epididymis join up to the **vas deferens (sperm duct)** which conducts sperms out of the testes.

Near the distal end of the sperm duct are the seminal vesicles, a pair of Cowper's glands and the prostate gland which are sometimes referred to as **accessory glands**.

- **Prostate gland** secrets mucus and a slightly alkaline fluid that is released during ejaculation. It makes sperms more active. It also neutralises the acidity of the vagina.
- **The Cowper's glands** secrete a clear, sticky, slightly alkaline fluid which cleans the urethra prior to ejaculation by neutralising any urine present.

- **The seminal vesicles** produce a mucus secretion which aids sperm movement. The resultant combination of secretions and sperm is called semen.

Semen is made up of sperms, sugars that nourish the sperms making them more active, mucus that forms a semi-fluid liquid that the sperms can swim in, alkaline substances to neutralise the acidic conditions in the urethra and vagina, and hormones which help sperms reach the ovum by causing muscular contractions of the uterus and oviducts.

The two sperm ducts join at the **urethra** which passes through the penis to the outside of the body. The urethra directs urine from the bladder as well as sperm from the vas deferentia out of the male body via the penis, at different times.

Note: The reproductive structure in human beings, just like in other mammals, is closely associated with part of the urinary system. These systems together are sometimes referred to as the **urogenital** system.

The **penis** is made up of capillaries, muscle and spongy erectile tissues. As part of the reproductive system, its role is to deposit sperm into the vagina of the female. This is possible due to the presence of specialised tissue known as erectile tissue. This tissue has spaces that fill up with blood during sexual excitement causing the penis to become rigid and erect, a process known as **erection**. During sexual excitement, the erectile tissue fills with blood, making the penis firm and erect.

The tip of the penis is called the glans. It has sensory neuron endings that are stimulated by friction to cause the expulsion of sperm with fluid known as semen through a process of **ejaculation**. There is a foreskin which covers the glans. This skin maybe removed during circumcision.

Health check!

Gently wash your penis each day. Carefully pull back and clean underneath the foreskin as well as the tip of the penis i.e the glans using clean water and a very gentle soap. Don't scrub the penis.

The sperm

A sperm cell comprises of:

- A head which has an acrosome containing lytic enzymes and a nucleus.
- The middle piece which contains mitochondria and a single centriole.
- A tail
- Nucleus

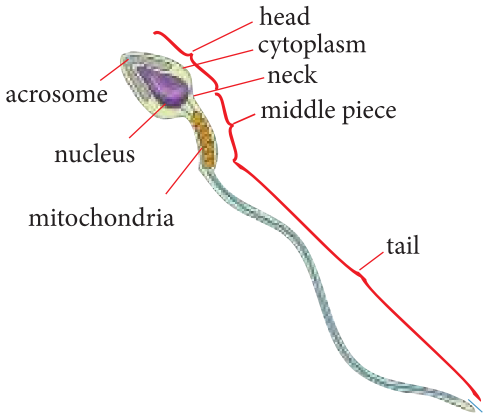


Fig 2.42: Structure of the sperm

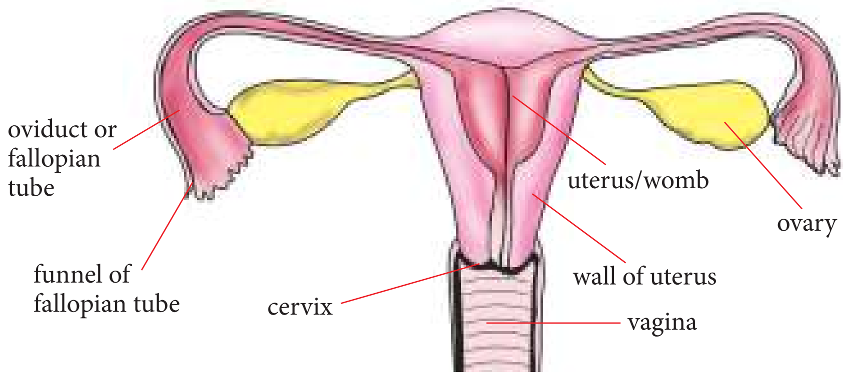
Adaptation of sperms

1. Long whip-like tail used for propulsion (swimming).
2. They are produced in large numbers to increase the chances of survival.
3. Large number of mitochondria helps to provide enough energy needed for propulsion.
4. The large nucleus helps the sperm cell to carry a lot of genetic information.
5. The lytic enzymes in the acrosome help to digest the egg membrane to facilitate fertilisation.

The female reproductive system

The main structures that make up this system are the ovaries, oviducts or fallopian tubes, uterus, cervix and the vagina.

(a) Front view



(b) Side view

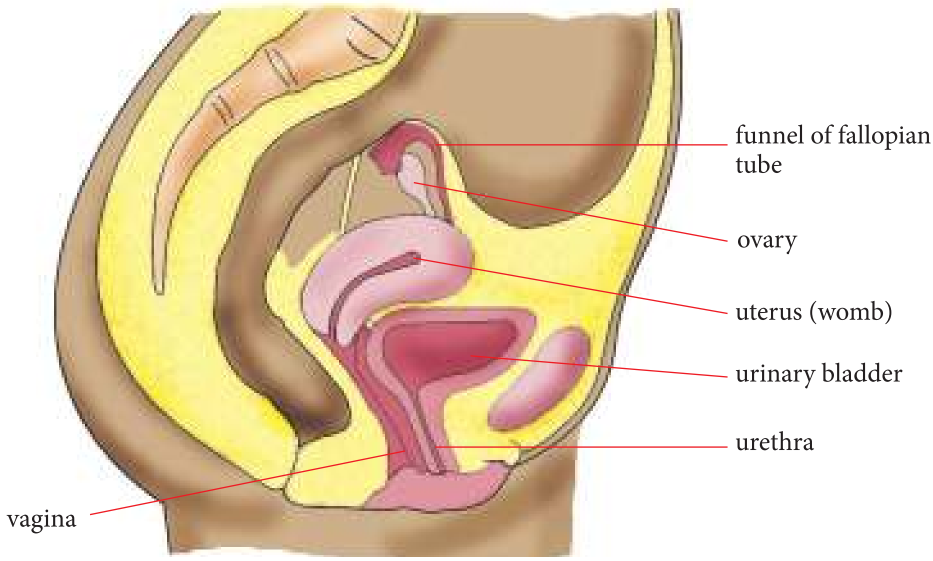


Fig 2.43: The female reproductive (a) front view (b) side view

The female gonads are the **ovaries** which produce the egg cells. They also secrete female sex hormones called **oestrogen** which is responsible for the female secondary sexual characteristics. The ovaries are located one on the left side of the uterus and the other on the right of the uterus. They are suspended in the abdominal cavity by ligaments. Inside the ovaries are immature eggs at different stages of development.

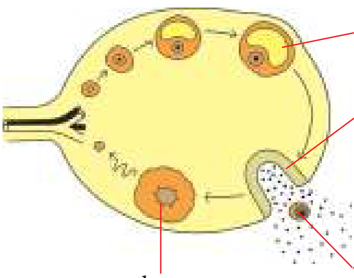


Fig 2.44: Section through ovary with ova at various stages of development

A baby girl is born with egg cells that are just starting to develop. Each month after puberty, one of these cells completes its development into an ovum. During development, each egg cell is in the form of a **graafian follicle**. The graafian follicle is a fluid filled structure containing one egg cell surrounded by a few cells known as follicle cells. In human beings, one egg is usually released once every month from alternating ovaries in a process known as **ovulation**.

The **oviducts or fallopian tubes** are tubes which lead from the ovaries to the uterus. It is through these tubes that the ova moves from the ovaries to the uterus. Each tube has an open ended funnel shaped part which lies next to the ovary.

Note that it is not attached to the ovary. The lining of the oviducts has ciliated cells. The movements of the cilia transport an egg cell towards the uterus. Fertilisation takes place in the oviducts.

Health check

Sexually transmitted infection of the oviducts may result in their becoming scarred and blocked. This may cause sterility.

If a fertilised egg implants itself in the oviducts, a tubal or ectopic pregnancy occurs. If the situation is not diagnosed and treated early, the tube ruptures and severe internal bleeding occurs which can cause death.

The oviducts join the uterus on the lower end. The **uterus** or **womb** is a hollow thick walled muscular organ with the size and shape of an inverted pear. It has a space inside it known as the uterine cavity. The outer layer of the uterus wall has thick muscles that contract strongly during birth. The inside layer of the uterus wall is made up of many blood vessels. It is called the **endometrium.** The uterine cavity leads to the cervical canal which extends to form a ring of muscle in the cervix. The cervix opens into the space of the vagina.

A fertilised egg implants itself in the thickened endometrium. The uterus contains a developing embryo during pregnancy until birth. It also enlarges during this time to occupy a large space in the abdomen. It shrinks rapidly immediately after childbirth.

The narrow neck of the uterus is called the **cervix**. It connects the uterus to the vagina. It is also sometimes referred to as the mouth of the uterus. It has a ring of muscle to close it and also a mucus plug. During pregnancy, the mucus plug seals the cervix and prevents entry of harmful microorganisms into the uterus. The ring of muscles remains contracted to keep the baby in the uterus. During birth, the ring of muscles relaxes to allow the baby to pass through to the world.

The **vagina** is a muscular tube leading from the cervix. It stretches during childbirth to allow the passage of the baby. The vagina opens to the outside through the vulva a (general name for the external genital organs. It is also a copulatory organ as well as a passage way for the baby during parturition.

The ovum

It is relatively large and round. It is made up of cytoplasm and nucleus surrounded by a membrane. The ovum is also surrounded by follicle cells.

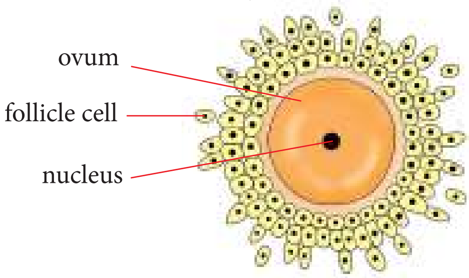


Fig 2.45: The structure of an ovum

The ovum is adapted to its function of being fertilised by the sperm and development of the zygote through:

- The egg cell is much bigger than the sperm.
- It has a chemical layer around the outside to stop more sperm getting in.
- It also contains one set of cytoplasm to survive on for the hours it takes the egg cell to reach the womb and form the embryo.

Check your progress 2.11

1. State the scientific terms that fit the following definitions.
   a) The sac of skin located outside the body wall in which the testes are located.
   b) The tube with a funnel-like end in which the released ovum from the ovary enters.
   c) The birth canal.
2. Trace the pathway of sperm leaving the male reproductive system.
3. Using a table, compare the adaptive features of the sperm and ova.
4. With illustrations, give the structure of an ovum.

2.11 The menstrual cycle

Activity 2.21: Investigating the menstrual cycle

Work in pairs

1. Using charts and computer animations provided:
   - Study the menstrual cycle.
   - Identify the stages involved.
2. Discuss the events involved in the stages and the interaction of hormones that control the menstrual cycle.
3. Present your work in class.

The facts

In the human female, a mature egg develops and is released from one of the ovaries every month. The average length of the **menstrual cycle** is 28 days. It can however be as short as 24 days or as long as 35 days. This cyclic event is known as the **menstrual cycle**. Before the release of the egg, the uterine lining becomes thick and is supplied with a dense network of capillaries in preparation for implantation.

If fertilisation does not occur, the new uterus lining and the egg are discharged from the uterus. This is called **menstruation** or **period** and usually lasts for about five days. The first day of the menstrual period can be regarded as day 1 of the menstrual cycle. During this time, the endometrium is shed from the uterus through the cervix and vagina together with some blood. After this event, four other main events occur:

- The healing and repair of the uterine lining (endometrium) after menstruation.
- Ovulation–the release of ovum from graafian follicle.
- Thickening of the uterine lining in preparation for implantation
- Menstruation occurs again if fertilisation does not occur.

Role of hormones in the menstrual cycle

After the endometrium has been shed from the uterus, the pituitary gland releases the **Follicle-Stimulating Hormone (FSH)**. This hormone stimulates the development of follicles in the ovary. One of these follicles develops into a *Graafian follicle*. Each egg in the ovary becomes surrounded by a layer of cells called **follicle cells**. When the FSH is released, it causes one of these follicles to undergo some change. It forms a space, accumulates some liquid, increases in size to develop into a structure called a **Graafian follicle**.

The ovary secretes **oestrogen**. When the oestrogen level rises in the blood to a certain point, it causes two events.

(i) One is the growth and replacement of the uterine lining shed during the previous menstruation with new tissue. This helps repair the lining of the uterus.

(ii) The second effect of oestrogen is that at its highest level in the blood, it triggers the anterior pituitary gland to release **Luteinising Hormone (LH)**. The LH stimulates ovulation and the formation of the *corpus luteum*.

Ovulation is the release of the ovum from the ovary. The level of LH rapidly rises in the blood. It triggers the process of ovulation at about the 14th day of the cycle.

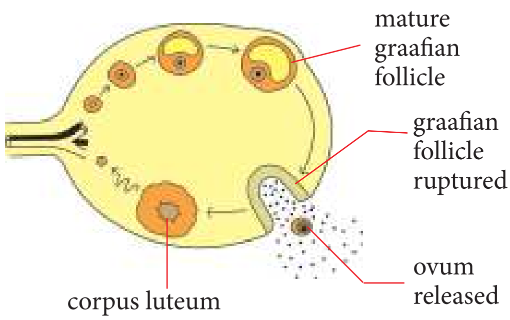


Fig 2.46: Ovulation

For ovulation to take place, a mature Graafian follicle moves to the surface of the ovary. It forms a bulge on the ovary surface.

It then ruptures and releases the ovum. It also causes the Graafian follicle to change into a yellow body or a **corpus luteum**.

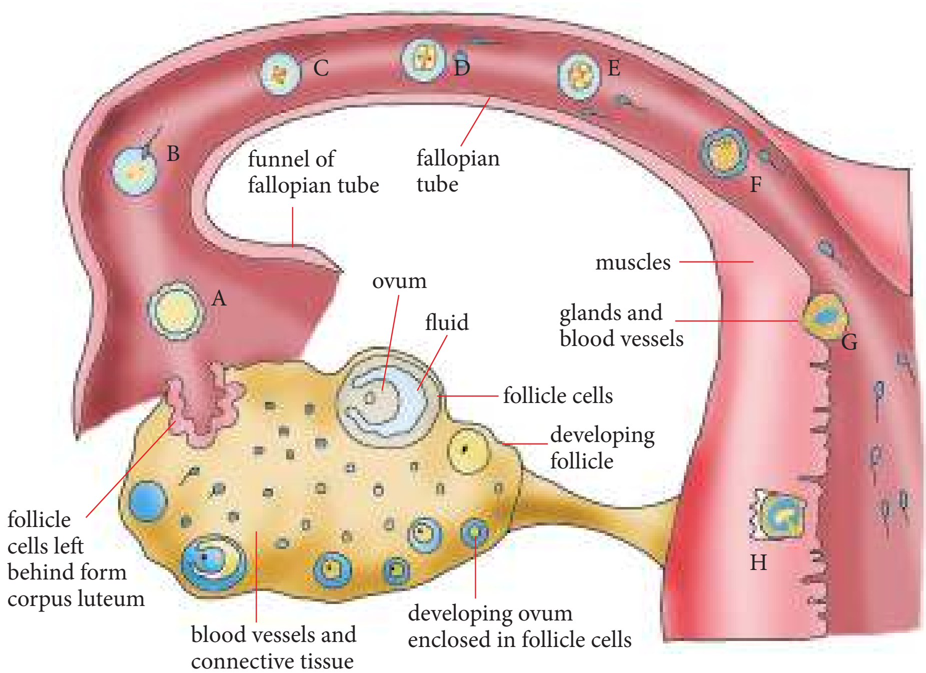
The Graafian follicle secretes both **oestrogen** and **progesterone**. The progesterone causes further thickening of the endometrium during which it is enriched with blood capillaries. This is in preparation for an embryo to be implanted. By this time the level of progesterone is quite high. This high level of progesterone inhibits further production of the FSH and also LH, from the pituitary gland. Less FSH means less oestrogen from the ovary, a low level of oestrogen will cause the pituitary gland to stop releasing LH.

The high levels of progestrone ensure that the thick endometrium layer in the uterus is maintained and no new follicle develops.

If the egg is not fertilised, the corpus luteum lasts for about 10 to 12 days and then it degenerates. The secretion of progesterone also stops.

The endometrium lining can no longer be maintained or protected so the capillaries break up and the endometrium is lost from the uterus with some blood.

The pituitary gland starts to secrete FSH again because the levels of progesterone go down. The pituitary gland is no longer inhibited to secrete FSH and the cycle repeats itself.



KEY

A — *Ovulation* **B** — *Sperm penetrates ovum*

C — *Sperm nucleus fuses with ovum nucleus (fertilisation)*

D, E, F — *Cell division of zygote which produces a ball of cells (embryo).*

G, H — *The embryo digests its way into the uterus wall and becomes completely embedded.*

Fig 2.47: Menstruation cycle

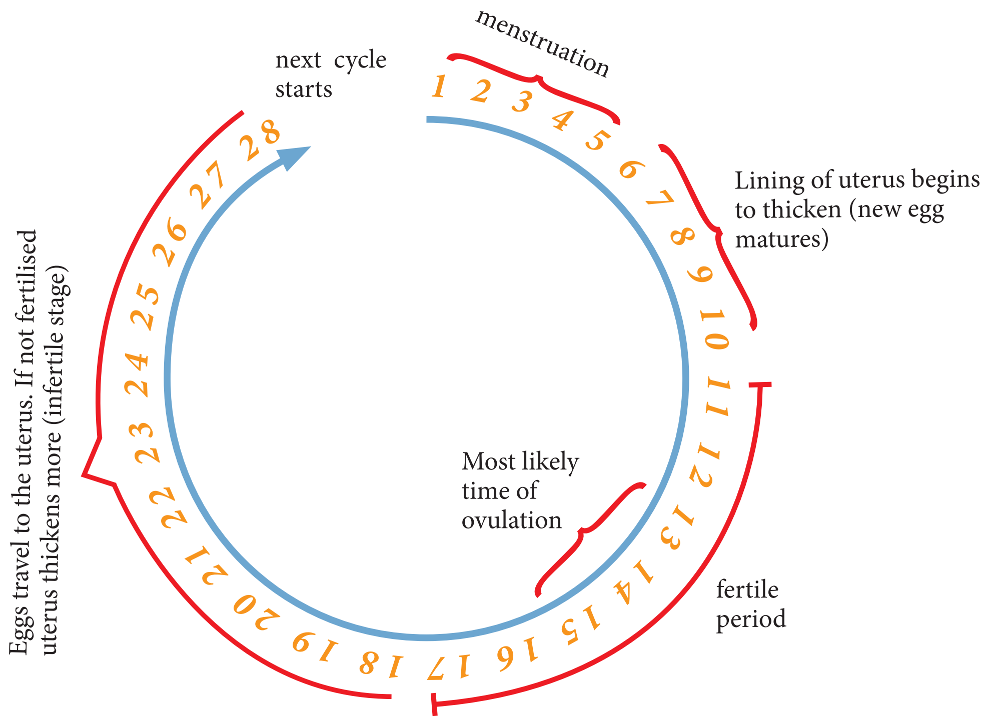


Fig 2.48: Menstruation cycle for 28 days

Check your progress 2.12

1. Explain why the uterine wall thickens and becomes spongy before ovulation.
2. On ovulation:
   A. The egg is fertilised
   B. An egg is released from a mature follicle sac
   C. The egg enters the uterus
   D. Menstruation begins
3. What is the importance of progesterone hormone inhibiting the secretion of FSH and LH?

2.12 Sex hormones

Activity 2.22: Discussion Activity

Work as a group

1. Using textbooks and the internet as your reference, with your friends, research on the roles of oestrogen and testosterone in the development of secondary sexual characteristic in females and males respectively.
2. Share your findings with the rest of the class.

The facts

Hormones are chemicals secreted by special glands in the body called **endocrine glands**. These hormones are transported via the blood stream to specific organs called target organs. The hormones cause specific effects in the target organs, which coordinate various body activities. Hormones that influence sexually related changes in the body are called **sex hormones.** These hormones control:

- The entire process of reproduction from the development of the reproductive features at puberty to pregnancy and birth.
- The shedding of the lining of the uterus (endometrium) every month i.e. menstruation.

As a child develops to puberty (its onset on average is between 13 to 15 years in males and 12 to 13 years in females), other features develop that further distinguish adult females and males. These are known as the **secondary sexual characteristics**. Development of secondary sexual characteristics is controlled by sex hormones. There are three different organs that release these hormones. These are the **hypothalamus**, the **pituitary gland** and the **gonads**.

The hypothalamus secretes a hormone which is taken to the anterior pituitary gland. Here, it stimulates the release of **Follicle Stimulating Hormone (FSH)** in females and **Interstitial Cell Stimulating Hormone (ICSH)** in males.

These two hormones are chemically identical but have different names because they have different effects in males and females.

In females, FSH stimulates the ovaries to produce oestrogen and progesterone. Oestrogen is responsible for the development of the female secondary sexual characteristics. The ovaries start producing eggs and this leads to the first menstruation also known as **menarche**. At first, it is irregular and unpredictable. Within a year, the hormone levels increase and monthly menstruation periods become more regular. In some people, pains may be experienced due to the progesterone hormone, which causes the uterine muscles to contract (muscle cramps).

In boys, the interstitial cell-stimulating hormone (ICSH) is taken to the interstitial cells in the testes.

It stimulates these cells to secrete testosterone which is responsible for the development of the male secondary sexual characteristics.

Check your progress 2.13

1. Give two functions of sex hormones.
2. What are secondary sexual characteristics?
3. Describe five secondary sexual characteristics in:
   - Females
   - Males

2.13 Fertilisation and implantation

Activity 2.23: Observing the process of fertilisation and implantation

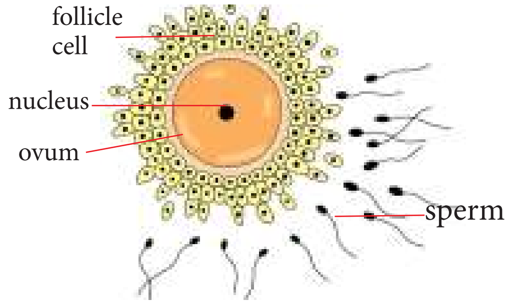
Work in pairs

1. Using charts and computer animations provided:
   - Observe the process of fertilisation and implantation.
2. Discuss the functions of the umbilical cord, placenta, amniotic sac and amniotic fluid.
3. Present your work in class.

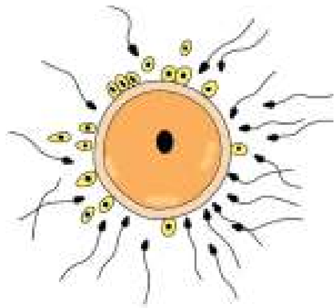
The facts

Fertilisation is the fusion of the male and female gametes. Once the sperms are ejaculated from the penis into the vagina, they swim and are also propelled through the cervix, uterus and into the oviduct where they may meet an egg. This normally occurs in the upper part of the oviduct.

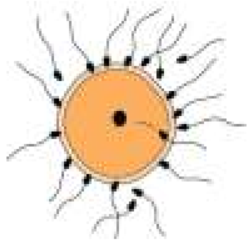
When the sperms and an ovum meet, the sperm heads stick onto the ovum. The action of the sperm causes the follicle cells surrounding the egg to disperse. Eventually, the nucleus of one sperm passes into the cytoplasm of the ovum along with the head and middle piece leaving the tail outside. The sperm nucleus fuses with the nucleus of the ovum. This fusion of the sperm and ovum nuclei is known as **fertilisation**. The egg membrane changes its structure after one sperm penetrates to prevent other sperms from entering the ovum. The fertilised ovum is called a **zygote**.



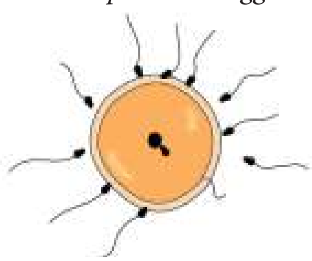
(i) Sperms meet ovum



(ii) Follicle cells dispersed



(iii) Sperm head penetrates egg membrane



(iv) Sperm and ovum nuclei fuse

Fig 2.49: The process of fertilisation

After fertilisation, a zygote is formed. The zygote moves down the oviduct. Movement of the ovum is aided by the beating of cilia found on the oviduct.

As it moves down the oviduct, it undergoes a series of cell divisions to form a hollow mass of cells known as the **blastocyst**. It develops finger-like projections called **villi** which attach it to the endometrium. It is then referred to as an **embryo**. The embryo uses the villi to absorb nutrients from the endometrium.

After implantation, one part of the blastocyst develops into the embryo while the outer layer of cells of the blastocyst develops into three membranes; chorion, allantois and amnion. **Chorion** lines the endometrium and provides a surface for the exchange of substances between mother and foetus.

Amnion is a sac that develops from the embryo and envelops it. It becomes filled with the **amniotic fluid** which plays the following roles:

- Gives the foetus physical support, allowing it to float and move around.
- Acts as a shock absorber protecting the foetus from mechanical injury.
- Lubricates the foetus and prevents it from dehydrating.

The **allantois** contributes to the formation of umbilical blood vessels which transport substances to and from the placenta. These membranes surround and protect the growing embryo until birth.

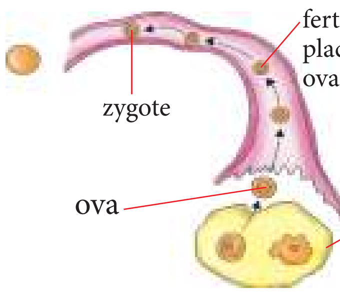


Fig 2.50: Implantation

The villi on the outer surface of the chorion extend into the lining of the uterus and form an organ called the *placenta*. A rope-like structure called the **umbilical cord** forms and connects the developing foetus to the placenta. The amnion, being the innermost of the membranes, completely surrounds the foetus like a balloon within a balloon.

A fluid called amniotic fluid fills up the amnion. It surrounds the foetus and keeps it moist, gives it a stable environment and cushions it from physical damage and shock.

The villi that develops from the blastocyst represent the beginning of the **placenta.** The placenta is made up of tissues and a large number of blood vessels. It has a disc like shape. The capillaries in the placenta unite to form a vein and two arteries which run in the umbilical cord from the placenta to the abdomen of the foetus.

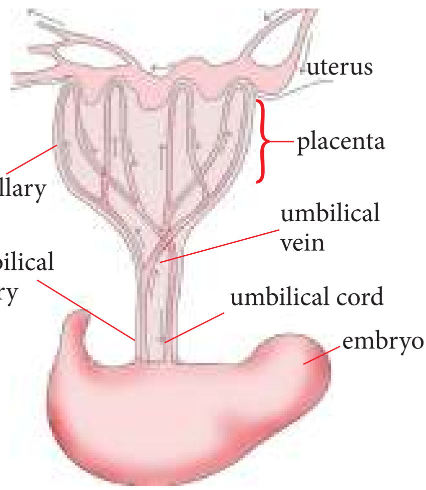


Fig 2.51: Placenta

The placenta forms the link between the circulatory systems of the foetus and the mother. It is made up of both foetal and maternal tissues and has a rich network of blood capillaries. The foetus is linked to the placenta by the umbilical cord which contains the umbilical artery and vein.

The placenta has **membranes** which separate the blood vessels of the mother and the foetus. These membranes are thin and hence allow dissolved oxygen, glucose and amino acids and salts in the mother's blood to diffuse into the blood vessel of the placenta. They also allow waste products such as carbon dioxide and nitrogenous wastes to pass from the placental blood vessels into the blood vessel of the mother.

Blood from the embryo is directed to the placenta capillaries through umbilical arteries. It has a high level of carbon dioxide and wastes like urea. Blood rich in nutrients and oxygen which have diffused into the placenta from the mothers' circulatory system are directed to the foetus through the umbilical vein.

- The membranes are selective in that they allow only certain materials to pass into the foetal circulation. In this way, they prevent some harmful materials from reaching the foetus.

Health check!

Substances such as drugs, alcohol and nicotine can pass through the placenta. Therefore, pregnant women are always advised not to take such harmful substances.

- Another role of the placenta is to produce hormones such as progesterone and oestrogen which assist in maintaining the pregnancy and preparing the body for birth.

Check your progress 2.14

1. What happens when fertilisation does not take place?
2. Only one sperm cell fertilises an ovum.
   (a) Why is this important?
   (b) How is it possible?
3. Suggest possible reasons that can hinder fertilisation.
4. Give three roles of the placenta.

2.14 Pregnancy, ante-natal care and birth

Activity 2.24: Investigating the stages in the development of pregnancy

Work in pairs

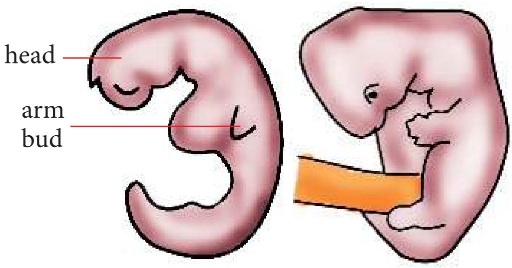
1. Using charts and computer animations, sequence the stages in the development of pregnancy.
2. Discuss the ante-natal care of a pregnant woman.
   - Is it okay for a pregnant woman to drink alcohol or smoke?
   - What takes place during birth?
3. Present your findings to the rest of the class.

Study questions

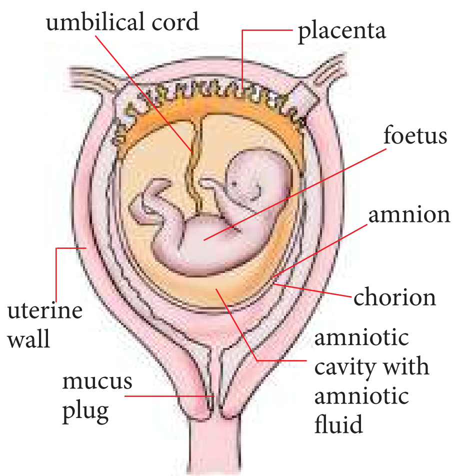
1. Are pregnant women allowed to diet?
2. Explain why pregnant women are not allowed to take any medicine unless prescribed by a physician?

The facts

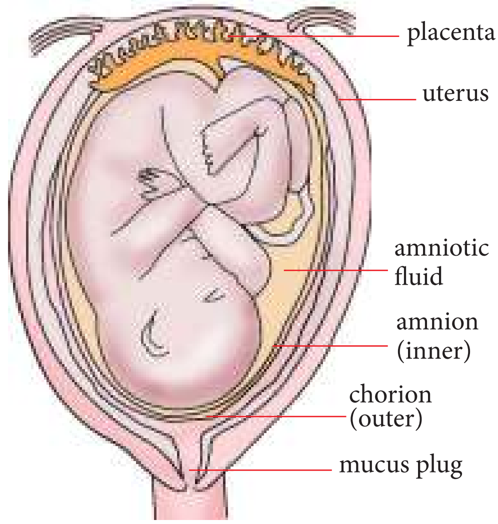
Pregnancy is also known as **gestation period**. This is the period within which the embryo grows and develops into a human being. In human beings, pregnancy lasts 38–40 weeks. During this period, the foetus develops as it is nourished by the mother through the placenta.



(a) 4 weeks *(b) 3 months*



(c) 5 months



(d) 9 months

Fig 2.52: Stages of foetal development during pregnancy

During foetal development, the following structural changes occur. The nervous system: the brain and spinal cord start to develop at the third week. The rhythmic contractions of the heart begin by end of week four as well as the circulation of blood. By around the seventh week, the brain starts to function.

Other vital organs like the kidneys, stomach and the liver become functional at eight weeks and the embryo is now referred to as a **foetus**. The genitals start to develop by the fourth month. From the sixth month, the foetus increases rapidly in size and by the 40^{th} week the baby is fully formed and can be born.

Ante-natal care

Ante-natal care is the care received from healthcare professionals during pregnancy. A pregnant woman should take extra care of her health for her benefit and that of the baby.

Her diet should have plenty of iron which is needed for the formation of haemoglobin. This is necessary to supply oxygen and nutrients to the placenta. She should also take plenty of calcium to be used in the formation of bones by the foetus.

- Name foods that contain iron and calcium that a pregnant mother should take.

Pregnant mothers should seek immediate medical attention in case of sickness. They should avoid getting some diseases like *Rubella* which could lead to disabilities and deafness of the foetus. Malaria is also a threat to pregnant women. They should sleep under treated mosquito nets always. Pregnant mothers are advised to attend ante-natal clinics without fail.

Pregnant women should also avoid certain types of clothes, for example, wearing high heeled shoes which could cause her to fall, and tight clothes. They should do light exercises like walking.

Pregnant women should avoid taking alcohol and smoking cigarettes since they harm the foetus and can result in giving birth to underweight babies or a miscarriage.

Birth

Before a baby is born, it normally turns upside down with its head just above the cervix. The process of birth begins with labour. The amnion ruptures and the amniotic fluid passes out through the vagina. The uterine contractions become stronger and more frequent and the cervix dilates to let the baby's head to pass through. The uterine contractions and the contractions of the abdomen together expel the baby out through the cervix and vagina.

The umbilical cord is then tied in two places and cut. After some time the placenta which is called the "after-birth" is also expelled from the uterus.

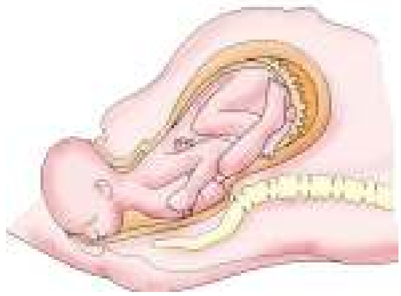


Fig 2.53: The process of birth

Check your progress 2.15

1. What terms fit the following definitions?
   a) The length of pregnancy.
   b) The lining of the uterus with smooth muscles.
2. Select substances that pass from the mother's blood to the foetus.
   Oxygen, carbon dioxide, drugs and nutrients
3. The umbilical vein carries _____ blood.
4. State the function of amniotic fluid.
5. Point out some of the things that pregnant mothers should avoid.
6. With illustrations, give stages of foetal development during pregnancy.

2.15 Cell division

Study the following flow-chart carefully.

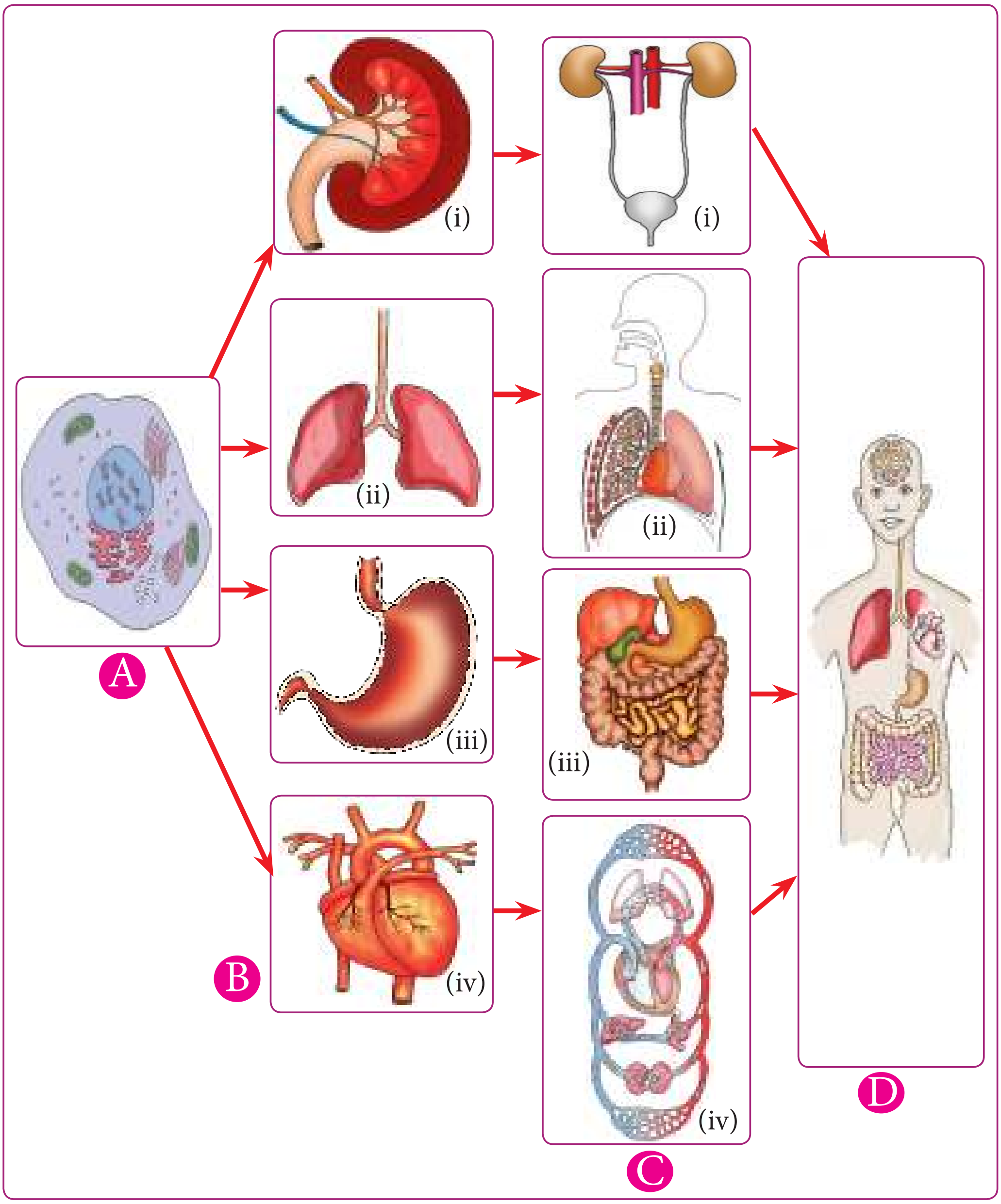


Fig 2.54: How multicellular organisms come about

Identify what **A**, **B**, **C** and **D** represent. What does the diagram tell you about how organisms come into existence? Use this information to predict what you are likely to learn in this topic.

Each one of us began as a single cell. This cell could not move, talk or think like we do. However, there was one thing it could do very well: **divide**. Divide it did!

Several times! The single cell became two, then four, then eight and so on. In time it became the person that you are now! You can now think on your own, talk, work and move your body parts. This is the amazing result of cell division. The processes of **mitosis** and **meiosis** happen during cell division.

2.16 Chromosomes

Activity 2.25: Research Activity

Work in pairs

You will be provided with textbooks and the video link: https://www.youtube.com/watch?v=tsVHWbXqum8

1. Carry out a research about chromosomes. Use the following lead questions:
   (a) What are chromosomes?
   (b) How are they formed?
2. Watch the video in the link above then answer the above questions.

The facts

Cells contain a **nucleus** which controls and regulates all the activities of the cell and heredity (passing on characteristics from parents to offspring). The nucleus is able to do all these because it has structures called **chromosomes**.

Chromosomes are thread like structures in the nucleus of plant and animal cells.

Chromosomes occur in the nucleus in pairs. These pairs are called **homologous pairs**. Homologous pairs of chromosomes have the same length and shape but with a different genetic composition. Chromosome numbers also vary according to the type of cells in the organisms. The difference in number of chromosomes in the same organisms depends on whether the cell is a normal body cell or a reproductive cell. The number of chromosomes in the nucleus of a plant or animal cell varies according to the species, for example, in human beings there are 46 chromosomes in the body cells (in 23 pairs).

All cells are formed from already existing cells by a process of **cell division**. When a cell is not dividing to form new cells, its chromosomes are not visible under the light microscope. It is said to be at rest. The chromosomes become visible only during cell division. This is because before the cell divides, each chromosome thread coils up to form a compact chromosome. When stained, such chromosomes are visible under the light microscope as shown in the diagram below.

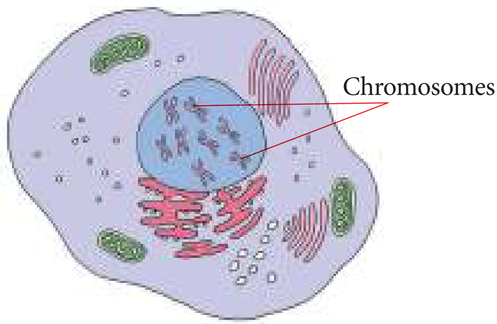


Fig 2.55: Chromosomes in a cell

The thread-like chromosomes coil up tightly to form thicker, shorter and more compact chromosomes just before cell division. They also appear to have split along their lengths to form two similar strands joined at their centres. These two strands are called **chromatids** and are joined at a point called the **centromere** as shown in Fig. 2.56.

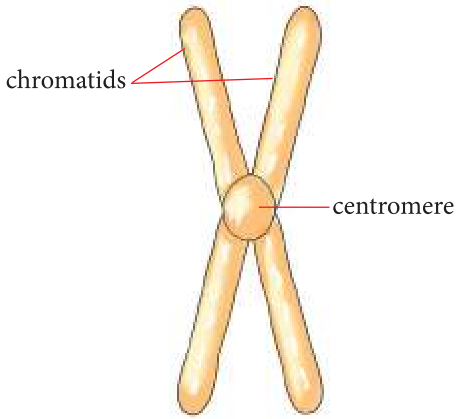


Fig 2.56: The structure of a chromosome

During cell division, the two chromatids separate, with each going into a separate cell as we shall see later.

Activity 2.26: Analogy of replication of chromosomes during cell division

Work as a group

Materials

- Two twisted ply wool
- A pair of scissors

Procedure

1. Cut about 6 inches of one piece of red wool and one piece of blue wool using scissors. Each piece represents a chromosome.
2. Make a knot in length of wool at its centre. (The knot represents the centromere). Twist the rope or wool.

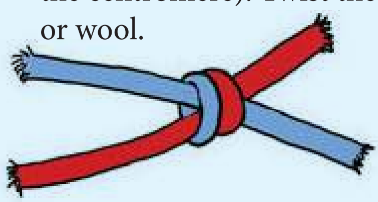


Fig 2.57: Piece of wool or rope representing a chromosome

3. Untwist the wool or rope from each end, leaving the untwisted wool pieces still joined at the knot. This untwisted wool with strands represents chromosomes which have split into chromatids. (This represent anaphase stage.)

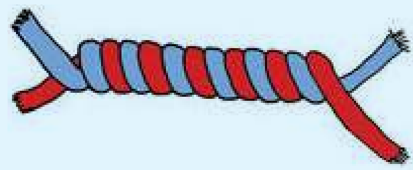


Fig 2.58: Twisted pieces of wool still joined together

4. Untie the knots and separate the untwisted strands from each other. (This represents the separation of chromatids at the centromere).

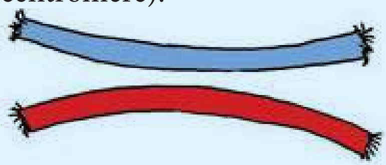


Fig 2.59: Untwisted pieces of wool no longer joined together

5. Take a piece of red strand and blue strand and put them together. Also take the other pieces of red strand and blue strand and put them together.

Study questions

1. How many sets of blue and red wool did you start with?
2. How many sets of blue and red wool did you end up with?
3. How was it possible to end up with double the sets of wool you started with?

4. What is the importance of the doubling of the sets of wool?
5. What does each procedure above represent?

Check your progress 2.16

1. A human being has _____ autosomes and _____ sex chromosomes.
   A. 23, 1
   B. 22 pairs, 1 pair
   C. 23, 23
   D. 2, 2
2. Each chromosome consists of two identical _________.
   A. genes
   B. nuclei
   C. chromatids
   D. bases
3. Which of the following is incorrect?
   A. Chromosome number is constant within individuals in a species in an ecosystem.
   B. Chromosome number is constant within different species in an ecosystem.
   C. Chromosome number is constant within somatic cells of an organism.
   D. None of the above.

Growth is one of the characteristics of all living organisms. It is an irreversible increase in mass. Cells originate from pre-existing cells. Therefore, during growth cells must increase in number through, the process of cell division. There are two types of cell division: **mitosis** and **meiosis**.

2.17 Mitosis

Activity 2.27: Examining the stages of mitosis using a squashed young onion root tip

Work in groups

Materials

- Germinating onions
- 1M HCL
- Test-tube
- Microscope
- Microscope slide
- Water
- Orcein dye (for staining)
- Tile
- Scalpel
- Glass rod
- Cover slip
- Blotting paper
- Forceps

Procedure

1. Cut off 0.5 cm from the end of a root tip of the onion.
2. Place it in a little 1M hydrochloric acid, which has been heated to 60°C in a test-tube.
3. Leave for 10 minutes. Remove the piece of root tip using forceps and wash it in running water.
4. Place it on a microscope slide and remove excess water using a blotting paper.

5. Place a small drop (0.5 cm diameter) of orcein stain on the tip, just enough to prevent it from drying up.

   Note: Orcein dye is used to stain chromosomes to make them visible.
6. Tap the root tip gently with a glass rod until no particles are seen. Remove any particles big enough to be seen. What is left should be a suspension of separated cells.
7. Lower a cover slip and leave for 10 minutes.
8. Use blotting paper to absorb any excess liquid. Avoid lateral movement of the slide.
9. Examine the preparation carefully under the high power objective of the microscope.
10. Draw observations in your drawing book.

Study questions

(i) Can you see any chromosomes?

(ii) What is the appearance of the chromosome?

(iii) Try to count the number of chromosomes in the cell in your preparation. What is the number in the onion?

(iv) Notice cells at different stages of mitosis.

(v) Identify two cells that are in each of the following stages of mitosis: prophase, metaphase, anaphase and telophase. Give one reason why you are able to identify a cell in each of these phases.

(vi) Draw one cell in each of these phases. Arrange the drawings in their correct sequence of the process of mitosis. Label as many structures as you are able to identify.

The facts

Mitosis is the process by which the nucleus of the body or somatic cell first divides into two daughter nuclei. Each daughter nucleus ends up with a set of chromosomes which are identical. After the nucleus divides, the cytoplasm then divides. This results in two cells that can exist independently. A simple way of understanding mitosis is by first following what generally happens to the chromosomes in the nucleus before following it up with what is also going on in the entire cell.

Normally, chromosomes only become clearly visible during cell division. The following is an outline of the main events that involve only the chromosomes in an imaginary cell with two chromosomes.

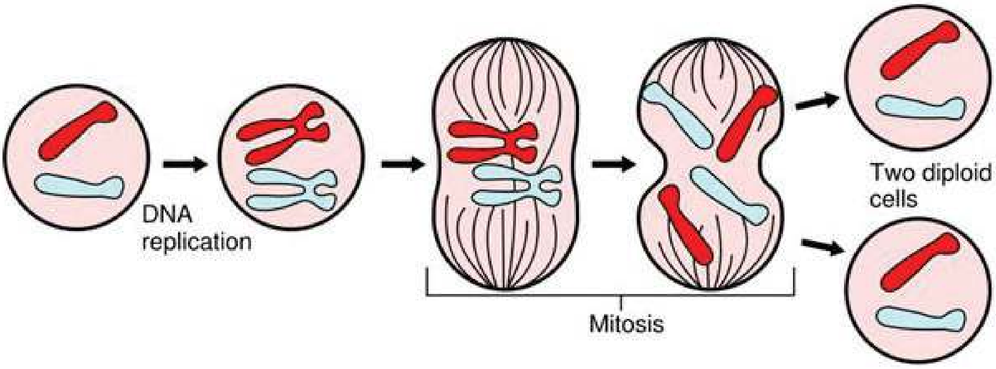


Fig 2.60: A generalisation of the process of mitosis

This way, it is possible for one set of chromosomes to be apportioned into each daughter cell that is formed when cells divide by mitosis. This means that each daughter cell can retain the original number of chromosomes in its nucleus.

The process of mitosis is an orderly sequence of events that happens to the whole cell. This sequence of events can be categorised into stages. Even though they can be studied separately, each is a continuation of the other; they are cyclic. They form a cycle of events, which can be divided into the following stages.

- Interphase
- Prophase
- Metaphase
- Anaphase
- Telophase

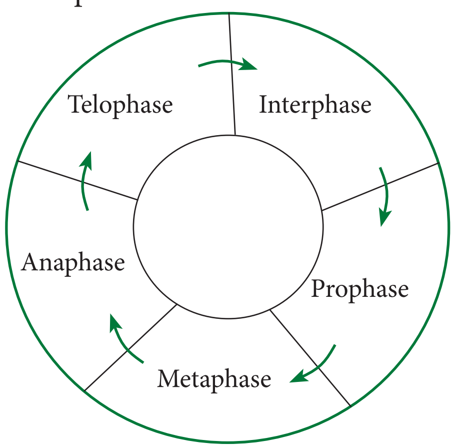


Fig 2.61: Process of mitosis

Did you know?

- Each chromosome duplicates itself by dividing into two strands called chromatids before the cell divides. The chromatids lie side by side and are joined together at a point called a centromere.
- These chromatids then separate from each other.
- Each chromatid is then called a chromosome and it goes into one of the new daughter cells.

Activity 2.28: Research Activity

Materials

- Yarn or a string
- Life savers
- 2 manila papers
- Scissors
- Felt pen
- Cellophane tape

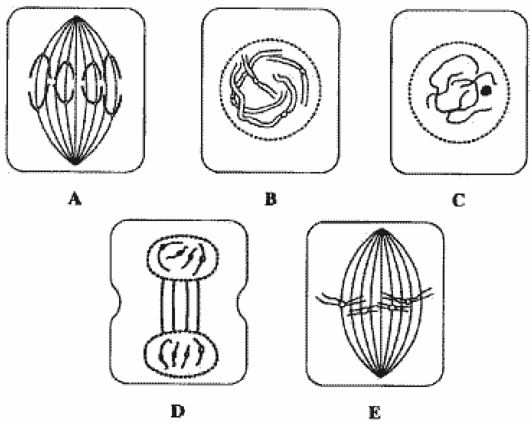
Procedure

Plan and carry out an investigation using the materials provided above to demonstrate different stages of mitosis.

Draw a well labelled diagram showing the arrangement of chromosomes in different stages of mitosis.

Study questions

1. What do you think a lifesaver and strings or yarn represent in this activity?
2. Suppose you were told to design an experiment similar to the one above, how could you design the experiment?
3. Highlight some of the importance of mitosis in an organism.
4. Arrange the following stages of mitosis in order and then identify the different stages.



Interphase

Interphase is the interval in the cell cycle between two cell divisions when the individual chromosomes cannot be distinguished. It was once thought to be the resting phase, but is actually the time when DNA is replicated in the cell nucleus.

In this phase, chromosomes are not visible under the light microscope. They appear as a twisted mass of thread-like structures called chromatin. During this stage, there is high metabolic activity as the cell generates energy in preparation for cell division. It is at this stage that the genetic material called DNA replicates itself. As a result, each chromosome replicates or doubles itself into two sister chromatids. New cell organelles are formed.

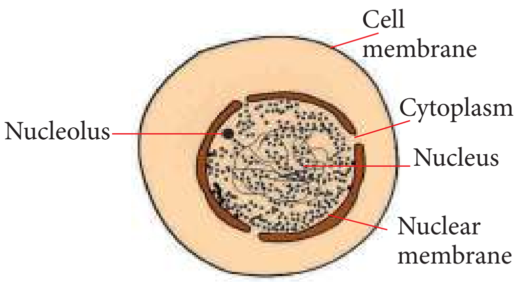


Fig 2.62: Interphase stage of mitosis

Prophase

The chromosomes become visible as long thin tangled threads. They gradually start to shorten and thicken and can be seen to comprise of two chromatids joined at the centromere. The centrioles, which are tiny structures that lie just outside the nucleus, move to opposite ends or poles of the cell. (Note that plant cells do not usually have centrioles). From these centrioles, strands appear. They form a star like structure. These strands are called spindle fibres and spread from one pole to the other. Together, they form a structure called the **spindle**.

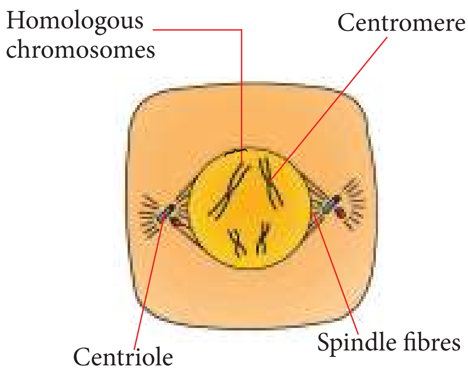


Fig 2.63: Early prophase stage of mitosis

At late prophase, the nucleolus disappears and the nuclear membrane breaks down leaving the chromosomes within the cytoplasm of the cell.

Metaphase

The chromosomes arrange themselves at the centre or the equator of the spindle. They become attached to certain spindle fibres at the centromere. These spindle fibres contract a little, separating the chromatids slightly apart. The following diagram shows chromosomes lined up at the equator.

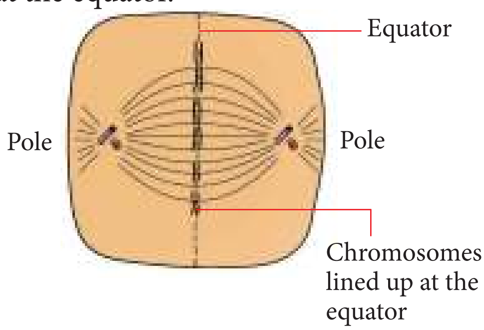
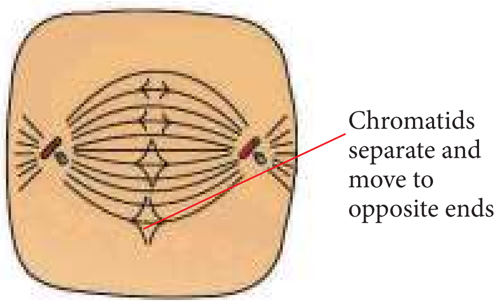


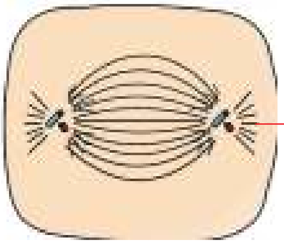
Fig 2.64: Metaphase stage of mitosis

Anaphase

The centromeres split and the spindle fibres shrink or shorten even more causing separation of the two chromatids. They move towards opposite ends or poles of the cell.



(a) Early anaphase

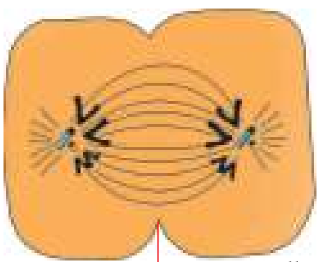


(b) Late anaphase

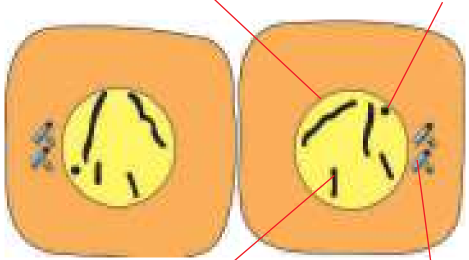
Fig 2.65: Anaphase stage of mitosis

Telophase

The chromatids reach their respective poles and become chromosomes. A new nuclear envelope or membrane forms. The spindle disappears and a new nucleolus forms in each new nucleus. The cytoplasm divides and the cell separates into two different cells. Each daughter cell has the same number of chromosomes as the original parent cell. Chromosomes regain their thread-like appearance and return to the resting interphase condition.



(a) Early telophase



(b) Late telophase

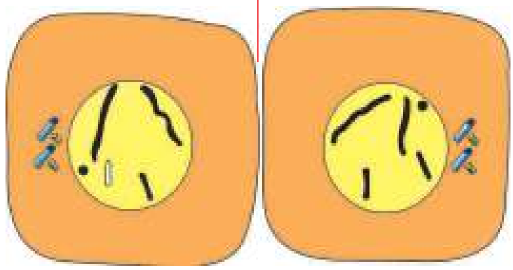


Fig 2.66: Telophase stage of mitosis

Importance of mitosis

Mitosis is important because it is responsible for:

(i) The process of asexual reproduction. This is due to the formation of new cells which retain the same number and exact copies of chromosomes as the parent cell.

(ii) Growth of new cells. New cells are formed through mitosis hence increase in number and contribute to the growth of an organism.

(iii) Replacement of damaged or worn out cells in the body. They are replaced by existing cells that divide by mitosis to provide additional cells.

In single-celled organisms like amoeba and other actively dividing cells, the process of mitosis is cyclic. This means that when the daughter cells formed mature, they too undergo mitosis.

Note

- Most animal cells are capable of dividing by mitosis when the need arises. Plant cells however are not all capable of dividing by mitosis. Only a specialised group of plant cells called meristem cells are able to do so.
- In specialised tissue like nerve tissue, division of cells stops once the cells mature. The existing nerve cells are too specialised to undergo mitosis to form replacement nerve tissue.

  This is why certain injuries to the spinal cord and the brain, which is made up of nerve cells, sometimes leave the patient paralysed permanently. This is because some of the nerves when severed cannot be replaced.

Disadvantages of producing large number of similar offsprings by mitosis

There is competition among offsprings for food and space.

In case of a natural calamity, all the offsprings can be swept away. All of the same traits also means all of the same weaknesses. Parasites and other predators that have evolved to kill just one of the organisms can take out the entire population.

Importance of mitosis in production of large numbers vegetatively

Asexual reproduction gives the ability to produce large quantities of offspring as this helps to fill up niches quickly and prevent intruders and competition from invading.

This increases the chance that the genes will be passed on to later generations. This is particularly important if disease is prominent.

Research project

1. Using the internet and textbooks, find out the disadvantages of producing a large number of similar organisms by mitosis.
2. Present your findings to the teacher.

Check your progress 2.17

1. Why does mitosis result in daughter cells with nuclei identical in chromosomal number and composition to the parent nuclei?
2. The spindle fibres are produced by the:
   A. Centrioles
   B. Nucleus
   C. Chromosomes
   D. Chromatin
3. Which of the following is correct?
   A. The chromosomes shorten and thicken during prophase.
   B. The nucleolus reappears following telophase.
   C. Interphase is characterised by little cellular activity, as the cell is resting to prepare for the next mitotic event.

D. All of the above.

4. A cell with 10 chromosomes undergoes mitosis. How many daughter cells are produced? ___ Each daughter cell has ___ chromosomes.

2.18 Meiosis

Activity 2.29: Examining stages of meiosis in the anthers of a flower

Work as a group

Materials

- Immature anthers (still enclosed inside the flower buds, for example, lily)
- Acetic Orcein dye (ten parts dye to one part HCL)
- Slides and cover slips
- Mounting needles
- White tile
- Hand lens
- Glass rod
- Filter paper/tissue
- Means of warming
- Forceps
- Microscope

Procedure

1. Take a flower bud and remove the enveloping sepals and petals. Expose the anthers. Do this on a white tile using a needle and forceps.
2. Use a hand lens to help you identify the anthers.
3. Remove one anther and place it on a clean microscope slide.
4. Add two drops of acidified acetic Orcein dye.
5. Squash the anther with a glass rod for a while and leave for a minute for the stain to penetrate the tissue.
6. Place a cover slip and press downwards gently. Remove excess liquid using a filter paper.
7. Examine the slide and look out for cells that have nuclei that is under division.
8. Try to locate and identify the chromosomes in different cells.

Study questions

1. Are there chromosomes that appear to have replicated?
2. What similarities and differences do you notice in various cells?

The facts

The process of meiosis is a type of cell division which reduces the number of chromosomes in a cell by half in order to form gametes i.e. sperm and ova. The original cell first divides into two cells. Each cell then divides further into two cells forming a total of four cells. Each of the four cells has half the number of chromosomes as the original cell. The four daughter cells are therefore **haploid**. These cells are similar but not identical. The process of meiosis occurs in two cell divisions.

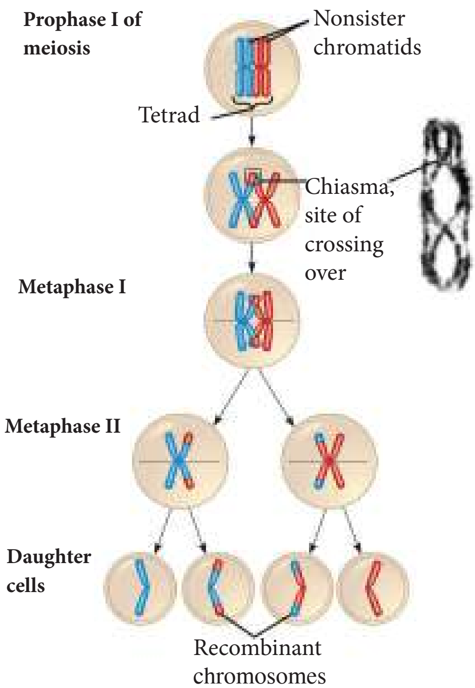


Fig 2.67(a): A generalisation of the process of meiosis

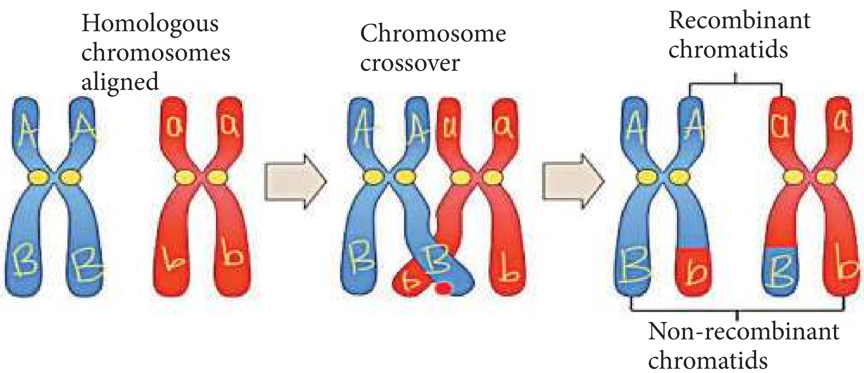


Fig 2.67(b): Process of crossing over

In human beings, the full set of 46 chromosomes is halved to 23 during meiosis, when sperms and eggs form. When the egg and sperm unite, they each contribute 23 chromosomes to the resulting embryo whose cells have the usual 46 (23 pairs). Meiosis also allows exchange of portions of chromosomes when the cells are dividing. This leads to genetic variation in offspring.

Meiosis occurs when gametes (reproductive cells) are formed. These gametes are formed in special organs that make reproductive cells in human beings. The reproductive cells are formed in the gonads: the testes in the male and ovaries in the female. In forming gametes, special somatic cells in the gonads undergo meiosis. In the testis, the resulting daughter cells are called sperms or spermatozoa and in the ovaries they are called ova or eggs.

In meiosis, two divisions of the nucleus and the cell occur. These are first meiotic division (I) and the second meiotic division (II). Just as we did in mitosis, we will first look at the outline of events that happen only to the chromosomes in an imaginary cell with two chromosomes.

(i) The chromosomes inside the nucleus split into two chromatids and the homologous chromosomes pair up.

(ii) The homologous chromosomes separate and the first meiotic cell division occurs.

(iii) The chromatids separate to form chromosomes and the second meiotic division takes place in a process similar to mitosis.

This is how it is possible to form a total of four daughter cells during cell division, each with half the number of chromosomes that the parent cell had i.e. the haploid number. Let us now study the whole process of meiosis as it involves the whole cell.

The stages of meiosis

The stages of meiosis form a cycle of events which can be divided into the following.

1. First meiotic division (*Meiosis I*)
    - Prophase I
    - Metaphase I
    - Anaphase I
    - Telophase I
2. Second meiotic division (*Meiosis II*)
    - Prophase II
    - Metaphase II
    - Anaphase II
    - Telophase II

Did you know?

The symbols I and II represent the first and second meiotic divisions. The interphase stage occurs between the two cell divisions.

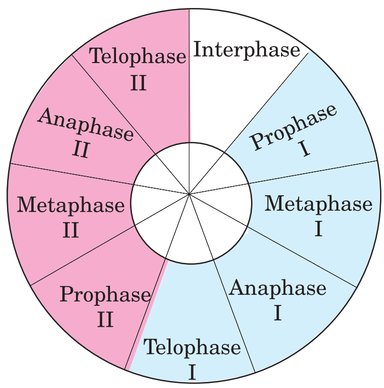


Fig 2.68: The cycle of meiotic division and stages that occur during meiosis

Research project

Using textbooks, the internet and other reference materials, carry out a research on different stages of meiosis. Write down summarised notes and draw the diagrams in each stage.

Significance of meiosis

Meiosis is important for various reasons.

1. Meiosis reduces the chromosome number by half, producing daughter cells with half as many chromosomes as the parent cell. This is important because it prevents the chromosome numbers from doubling in each generation: the daughter cells have haploid number of chromosomes.
2. It ensures that when sexual reproduction takes place, genetically varied offspring that are different from parents and from one another are formed. A different trait in an offspring may enable it survive better than the parents when environmental conditions become adverse. This is possible because genetic variability results from:
   (i) Random fertilisation of eggs by sperms.
   (ii) Large numbers of possible arrangement of chromosome pairs at metaphase I, which increases the possible combinations of chromosomes in the gamete cells produced.
   (iii) Crossing over during prophase, which enables the exchange of corresponding segments between two homologous chromosomes.

Comparison between mitosis and meiosis cell division

Activity 2.30: Class Discussion

Work as a class

1. Engage with classmates about the differences between meiosis and mitosis. Use the following lead questions.
   (a) The number of daughter cells and chromosomes.
   (b) Pairing of homologous chromosomes.
   (c) Occurrence of crossing over and chiasmata.
   (d) Significance of the process.
2. Present your findings to the rest of the class.

Similarities

1. Both mitosis and meiosis involve nuclear division that results in the formation of new cells.
2. DNA should be replicated before both meiosis and mitosis take place.
3. Both have the same stages (prophase, metaphase, anaphase and telophase) but there occurs some specific events like crossing over (recombination) in meiosis.
4. Fundamental events and processes are the same in both meiosis and mitosis.
5. Both mitosis and meiosis are associated with cytokinesis. Cytokinesis occurs during telophase stage.
6. Meiosis II is similar to mitosis.

Differences

Table 2.4: Comparison of mitosis and meiosis

Mitosis	Meiosis
It produces daughter cells and is responsible for: • growth • repair • asexual reproduction	It produces gametes with half the chromosome number (haploid). This: • Ensures that organisms formed due to sexual reproduction retain cells with the double number of chromosomes. • Brings about genetic variation.
Two daughter cells formed.	Four daughter cells formed.
Daughter cells are identical to the parent.	Daughter cells are not identical to the parent.
The number of chromosomes are retained.	The number of chromosomes is halved.
Homologous chromosomes do not pair up.	Homologous chromosomes pair up in prophase I.
Chiasmata do not form. No crossing over occurs.	Chiasmata is formed and crossing over may occur.

Check your progress 2.18

1. Why does meiosis result in a daughter nucleus that is different from the parent nucleus?
2. Crossing-over occurs during:
   A. anaphase I
   B. metaphase I
   C. prophase I
   D. prophase II
3. Which of the following distinguishes prophase I of meiosis from prophase of mitosis?
   A. Homologous chromosomes pair up
   B. Spindle forms
   C. Nuclear membrane breaks down
   D. Chromosomes become visible

2.19 Growth and development in plants and animals

Study the diagrams below carefully.

Fig 2.69: Growth in plants and animals

From the diagrams above, you may have noticed that human beings, just like other animals and plants, grow gradually to become mature organisms.

Activity 2.31: Investigating the process of growth

Work in pairs

1. What do you notice?
2. Why do you think this process is important in both plants and animals?
3. What is the difference between growth and development?

The facts

Growth refers to the irreversible (permanent) increase in size and mass of an organism.

Development refers to the changes in the complexity of an organism. Development involves differentiation and formation of various tissues that perform specialised functions. Growth is ***quantitative***. It can be measured. For example, ***height***, ***volume*** and ***mass*** can be measured. Development is ***qualitative.*** It cannot be measured. For example the emergence of a new structure and ripening of fruits.

The process of growth

Activity 2.32: Investigating the process of growth

Work as a group

Materials

- Maize/beans seeds
- School garden
- Hoe
- Fertilizer

Procedure

1. At your free time, visit the school garden.
2. Using a hoe, plant maize/ bean seeds.
3. Apply fertilizer to part of the plantation and leave the rest without applying fertilizer.

4. Observe and draw your observation.

Study questions

1. Explain the difference between the plantation where fertilizer was applied and where fertilizer was not applied.
2. Explain what happens in each stage of growth.

The process of growth involves assimilation, cell division and cell expansion.

(a) Assimilation

This is the incorporation of the materials absorbed from the surrounding into the cell metabolism. The materials (food and respiratory gases) are used to make new structures of the cells.

(b) Cell division

This is the basis of growth in all multicellular organisms. There is division of cell nucleus and cytoplasm with duplication of nuclear material. Cell division results in increase in the number of cells.

(c) Cell expansion

Cells increase in size when they take in water by osmosis. The individual cells take in water in their vacuoles and expand.

Types of growth

There are several types of growth namely allometric growth, diffuse growth, localised growth, intermittent growth, isometric growth, determinate growth and indeterminate growth.

1. Allometric growth

This is the type of growth whereby different parts of the body of an organism grow at different rates and stop growing at different times. For example, in humans, the brain grows faster initially than other organs and virtually stops soon after the age of five while the rest of the body continues to grow for another 15 years or so. In plants, flowers grow faster than the vegetative parts.

2. Diffuse growth

This is the type of growth whereby growth occurs all over the body of an organism, for example in mammals.

3. Localised growth

This is the type of growth whereby growth occurs in certain regions. For example, in plants, growth takes place at the tips of roots and shoots. These tips are called ***meristems***.

4. Intermittent growth

This is the type of growth in arthropods in which growth takes place in a series of stages called ***instars***. For example in insects, an egg hatches into a larva which then develops into a pupa and finally into an adult (imago).

5. Isometric growth

This is the type of growth whereby all body organs grow at the same rate, for example in fish.

6. Determinate growth

This growth is seen in individuals which stop growing when a certain body size or age is attained, for example, growth in mammals, birds and annual plants.

7. Indeterminate growth

This is the type of growth shown by organisms that do not stop to grow. For example, organisms such as perennial plants, shrubs, corals, fish and reptiles show unceasing growth.

Measurement of growth

Activity 2.33: Measuring growth in plant

Work as a group

Materials

- Pots or planting trays
- Compost
- Soil
- Seeds
- Source of light

Procedure

1. Plant your seeds in the mixture of soil and compost in a pot or planting trays and place them in a well-lit location.
2. Keep all the pots in the same setting.
3. Record on a daily basis the number of seeds that have germinated, plant growth and observe plant health such as colour, vigour or damage due to pests.
4. Decide on the measurement to use as indications of plant growth, either the plant height, number and dry weight.

Growth can be estimated by measuring any suitable parameter of an organism at suitable intervals of time. Growth can be estimated by measuring height, mass, volume, length, total fresh and dry weight.

(a) Total fresh weight

This method involves weighing the whole organism at regular intervals. This is an easy method used to estimate growth for large animals including man. This method does not cause injury to the organism. Fresh weight measurements are influenced by changes in water content of the body and therefore do not give accurate results.

(b) Dry weight

This method involves killing the organism and heating it at 110˚C to a constant weight to remove water. This method is more accurate since it indicates the increase in weight due to synthesis of different materials irrespective of water content.

(c) Volume

This method involves placing an organism in a water-filled container and determining the water displacement using an overflow can. The volume of the water displaced by the organism is measured using measuring cylinders.

Alternatively, the volume of the organism can be calculated arithmetically from surface measurements. The disadvantage of this method is that organisms are often irregular and changes in fresh weight which can be misleading.

(d) Length

This method of measuring the length of the organism is reliable if growth occurs mainly in one direction like in flowering plants. This method is advantageous in that it does not injure the organism. The main disadvantage of this method is that it ignores growth in other directions such as width and girth, which can be significant.

(e) Number

This method is used to measure growth of unicellular organisms such as bacteria, algae and protozoa. This method involves collecting and counting the number of organisms in samples of fixed volume periodically.

The total population can be estimated as follows:

$$\frac{A \times B}{C} = N$$

Where

A – Average number of organisms per sample

B – Total volume of sample

C – Volume of sample

N – Total population number

Activity 2.34: Investigating the developmental stages of a toad

Work as a group

Materials

Eggs of a toad in a water pond.

Procedure

1. Collect eggs of a toad from a pond and put them in a well-prepared aquarium. You may investigate directly from a school pond.
2. Make regular observations of the eggs until they hatch.
3. Observe the body structures, feeding habits and movement of the tadpoles.
4. After the process of metamorphosis is complete, the adult toad climbs on stones ready to move. Make final observations before releasing it to its terrestrial environment.

Study questions

1. How long does it take for the eggs to hatch into tadpoles?
2. State the differences between the tadpoles and the adult toad.

Limitations in estimating growth

If a single, linear dimension parameter such as height or length is measured, it fails to put into consideration the growth in other directions, for example lateral growth.

There is lack of accuracy while measuring the volume of an organism with an irregular shape.

Growth shows irregularities as a result of fluctuations in the environmental factors such as nutrients.

When growth is measured using dry mass method, it involves killing the organism, which may not be applicable in most cases. For example, human beings cannot be killed.

Measuring the size or mass of an organism fails to recognise that different parts of the organism may grow at different rates and stop growing at different times.

The growth curve

If a growth parameter such as height or mass is plotted against time, a growth curve is obtained. The pattern of growth tends to be the same in most organisms.

Growth tends to be slow at first, then it speeds up and finally slows down as adult size is reached. This gives an **S**-shaped curve called ***sigmoid curve*** *(Fig 2.70)*.

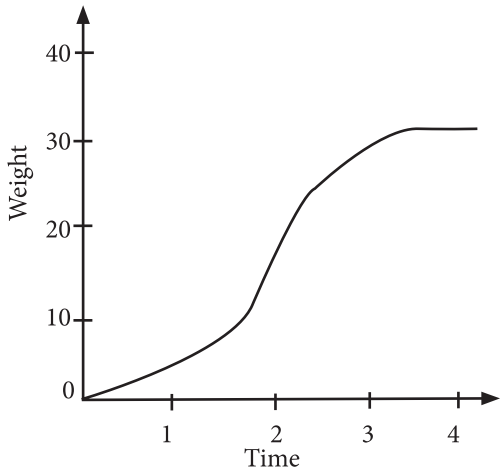


Fig. 2.70: Growth curve

Phases of growth

There are four phases of growth namely lag phase, exponential phase, decelerating phase and stationary phase.

1. Lag phase

This is the initial stage where little growth occurs. In some organisms there might be slight decrease in growth. For example in flowering plants, there is a loss of dry weight during seed germination. Growth is slow because:

(a) The number of dividing cells is small.

(b) The cells have not yet adjusted to the environment.

2. Exponential phase

This is the stage where maximum growth occurs. In plants it is a period when green foliage increases in amount. Growth is rapid because:

(a) There is a large number of dividing cells.

(b) The rate of cell increase is greater than the rate of cell death.

(c) The cells have adjusted to the environment.

(d) Environmental factors such as food and space are not limiting and hence the cells are not competing for such resources.

3. Decelerating phase

This is the stage at which the maximum peak is reached and growth starts to decline. This is because of the limiting factors that set in, both internal and external factors. Growth declines because:

(a) Most cells have fully differentiated and hence cannot undergo more differentiation.

(b) There is limitation by environmental factors. For example, shortage of nutrients (food), competition for respiratory gases, and space and accumulation of waste products, which could be harmful to the organism.

(c) The rate of cell death is more than the rate of cell increase.

4. Stationary phase

This stage is also known as ***plateau***. This is the stage when growth ceases (stops) and the parameter under consideration remains constant. The rate of cell increase equals the rate of cell death. In micro-organisms, the number of individuals dying is approximately equal to the number of new individuals being produced.

Growth rate curve

A growth rate curve is obtained when an increase in a given growth parameter at successful intervals is plotted against time. In most organisms, growth rate increases steadily until a maximum is reached, after which it gradually falls giving a bell-shaped curve (Fig 2.71).

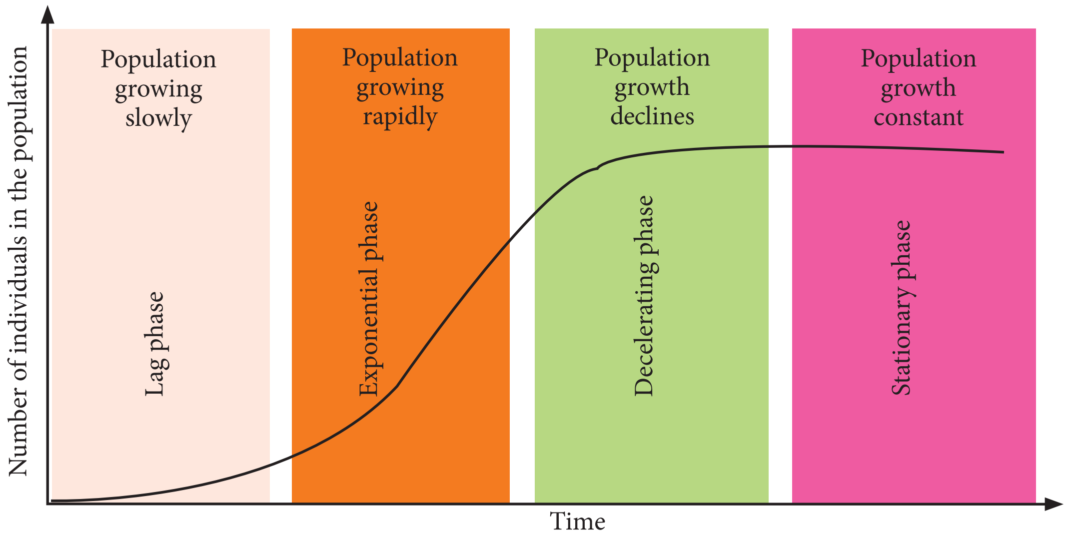


Fig. 2.71: Growth rate curve

Percentage growth curve

Percentage growth refers to the increase in growth over a period of time expressed as a percentage of the growth that has already taken place. For example, between the ages of one and two years, the baby's mass may increase from 8 to 10 kg. The absolute increase is therefore 2 kg.

The percentage increase is $\frac{2}{8} \times 100 =$ 25%.

To compare this, let us take another example.

The mass of a teenager increased from 50 kg to 55 kg, the absolute increase being 5 kg. The percentage increase is

$\frac{5}{50} \times 100 = 10\%$. This shows that a baby, though it puts on much less mass in a year than a teenager, has a higher percentage growth rate. If percentage increase is plotted against time, a percentage growth curve is obtained (Fig 2.72). The graph shows that growth is fastest at the beginning of life, after which it gradually slows down. This is true for most organisms, both plants and animals.

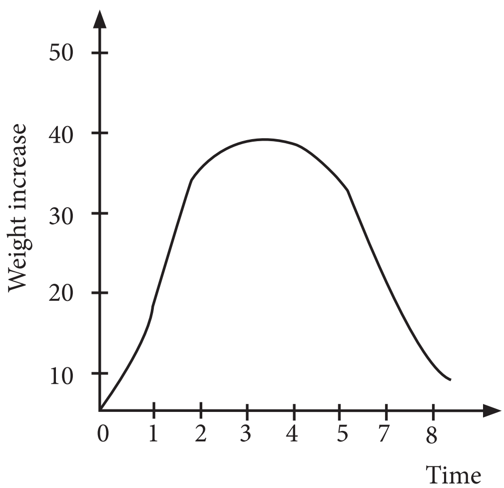


Fig. 2.72: Percentage growth curve

Factors that regulate growth

There are factors within the environment that limit an individual or a population from growing indefinitely. These factors are called limiting factors and are either ***density dependent*** or ***density independent***.

Density–dependent factors

The effectiveness of density–dependent factors depends on the number of individuals per unit of space. For example, the amount of food available dictates how many individuals are able to exist in that unit of space.

Density–independent factors

These are factors that do not depend on the number of individuals. For example, the temperature of a place does not dictate the number of individuals in that place.

External factors that affect growth

1. Food and water

In areas where food and water are adequate, competition is reduced and the population increases. In case of shortage of food and water, competition sets in and most individuals die due to lack of food and/or water.

Water is a requirement for photosynthesis by plants. In case of shortage of water, plants make less food. This results in reduced rate of growth.

2. Light

Light is particularly important to green plants, which use it during photosynthesis to make food. Plants compete for light with each other in areas of dense vegetation.

3. Space

Organisms compete for breeding sites, shelter against predators and harsh environmental factors such as excessive heat. Lack of enough space results in accumulation of waste products, which could be harmful to the organism and may even result in death.

4. Accumulation of toxic wastes

High concentrations of poisonous substances such as nitrogenous wastes (ammonia), gases such as carbon dioxide, carbon monoxide and sulphur dioxide can severely affect the lives of individuals.

5. Disease outbreak

Overcrowding results in rapid spread of an infectious disease within a population. An outbreak of an epidemic disease in overcrowded areas can wipe out the whole population.

6. Nutrients

Plants absorb nutrients from the soil or the surrounding environment. Nutrients are used for growth. Lack of adequate nutrients leads to reduced growth.

7. Oxygen and carbon dioxide

Oxygen and carbon dioxide are called respiratory gases. Oxygen is required by all living organisms during respiration to release energy. Plants require carbon dioxide as a raw material for the process of photosynthesis. Pollution of the environment may cause reduction of these gases. For example, spilling of oil in water bodies reduces the penetration of gases in water, hence affecting the aquatic life.

8. Predators and parasites

A predator kills another organism for food. The organism that is killed for food by predators is called ***prey***. A parasite is an organism that obtains its nutrients from the tissues of another living organism. An increase in the number of predators decreases the number of the prey. A parasite may cause diseases, transmit diseases, deprive the host food or damage the host, which could lead to death.

Internal factors that affect growth

1. Growth hormones

Hormones are chemical substances that affect growth. In plants, the growth hormones are called ***auxins*** and are found at the apical meristems. Auxins promote growth at the tips of roots and shoots.

Animals also have growth hormone which influence the rate of overall growth of the body. In humans, the growth hormone is secreted by the pituitary gland in the brain.

2. Hereditary factors

These are also known as genes and are found in the chromosomes inside the nucleus of cells. They control the physical characteristics including growth of the organism.

3. Psychological factors

Overcrowding leads to psychological stress, which makes individuals reluctant to breed. In some animals such as birds, overcrowding causes the individuals to acquire and defend their territories. Psychological factors may therefore, affect the breeding rates of individuals or a population hence affecting the size of that population.

Activity 2.35: Measuring the growth rate of a laboratory mouse

Work as a group

Materials

- Little newborn mice
- Weighing balance

Procedure

1. Take the little newborn mice and weigh each one separately on the day of birth.
2. Repeat the weighing after every two days until there is no further increase in weight. Weigh before feeding.
3. Plot your results in the form of a graph with age in days on the horizontal axis and weight on the vertical axis.

Study questions

1. What is the shape of the graph you obtain?
2. What is the importance of taking the weights before feeding?

Check your progress 2.19

1. Define the following terms:
   (a) Growth
   (b) Diffuse growth
   (c) Localised growth
2. State three importance of growth to organisms.
3. Why is growth rate slow at the initial stage of development?

4. How does sunlight affect growth of plants?
5. How does competition of resources affect growth?
6. Giving examples, differentiate between density-dependent and density-independent factors.
7. A person eats a heavy meal and finds his weight has increased. Would this increase in weight constitute to growth? Why?
8. When does negative growth occur?

Growth and development of shoots and roots

In plants, growth and development take place in certain localised regions called ***meristems.*** The main meristems are located at the tip of the shoots and tip of the roots, and they are called ***apical meristems***. It is in the meristems that active cell division and differentiation occur.

2.20 Primary and secondary growth

1. Primary growth

Primary growth in plants refers to the increase in length of the shoot and root. The increase in length is brought about by cell division, cell elongation and cell differentiation.

(a) Cell division

The meristematic cells undergo rapid mitotic divisions all the time. One of the daughter cells formed by the mitotic cell division remains meristematic and continues to divide. The other daughter cell absorbs water and expands and does not divide (Fig 2.73).

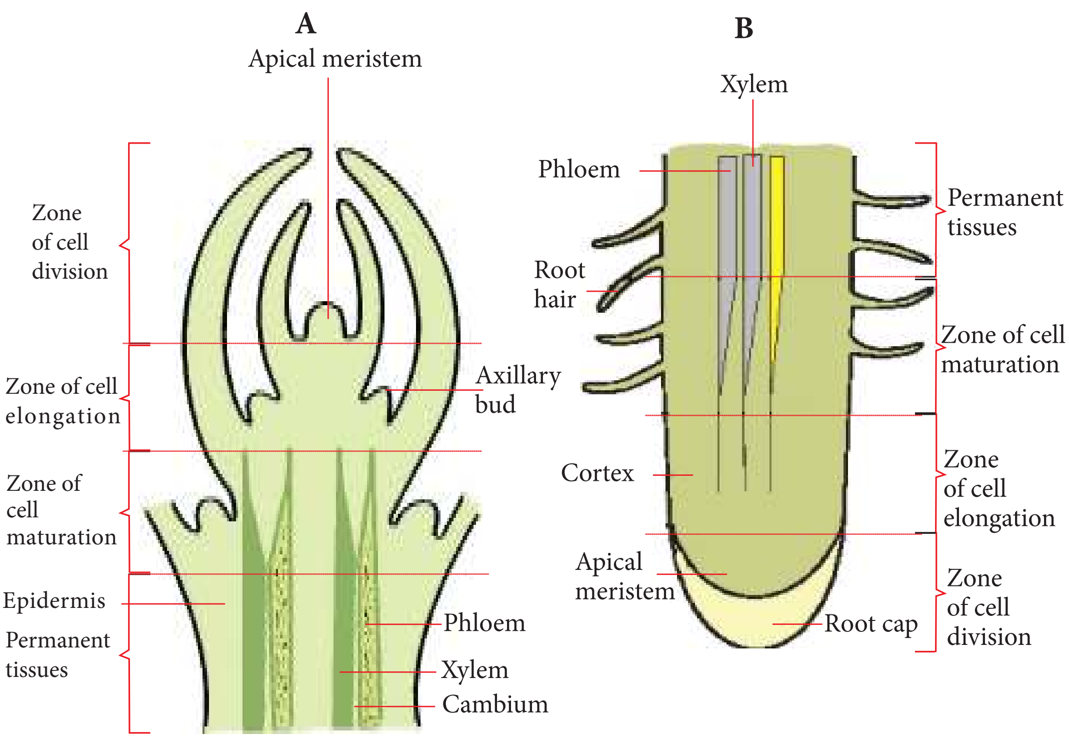


Fig. 2.73: Longitudinal sections of meristematic regions of (A) a shoot tip and (B) root tip

(b) Cell elongation

The cells behind the tip draw in water. They absorb water by osmosis, develop a vacuole and expand resulting to cell elongation (Fig 2.73).

(c) Cell differentiation

The elongated cells undergo cell maturation to form specialised tissues such as vascular tissues and parenchyma tissues. In the stem, the apical meristem gives rise to ***leaf primordium*** on either side. The leaf primordium grows fast and envelops (encloses) the apical meristem and younger leaf primordium forming what is known as ***apical bud***.

The angle between the main stem and the leaf is called ***axil***. The lateral (auxiliary) bud develops with its meristematic cells at the tip dividing, elongating and differentiating, forming the side branches (Fig 2.73). The point of attachment of a leaf to the stem is called the ***node.*** The region between two nodes is called an ***internode***.

The cells at the zone of cell maturation are arranged in circles and form the ***vascular bundle***. The vascular bundle consists of the primary xylem to the inside and primary phloem to the outside.

The cells between the epidermis and the vascular bundle are called ***parenchyma cells*** and form the cortex. To the inside of the vascular bundle are parenchyma cells that form the ***pith***.

In the roots, the apical meristem is protected by the ***root cap*** (Fig 2.73). The cells in the meristems are small, thin-walled, with relatively large nuclei and minute vacuoles. These cells undergo rapid mitotic division. They absorb water and increase in length due to the enlargement of the vacuole. Some of the cells differentiate into root hairs, which provide a surface area for absorption of water and mineral salts.

2. Secondary growth

Secondary growth in plants refers to the increase in thickness (girth) of woody stems and roots (Fig 2.74). Secondary growth does not occur in herbaceous annuals and biennials, which only live for one or two years. The cells between the xylem and phloem form the ***vascular cambium***.

The cells of the cambium retain the ability to divide by mitosis. This means that the cells of the cambium are meristematic cells. The new cells formed by the vascular cambium mature as ***secondary xylem*** to the inside and ***secondary phloem*** to the outside.

The new and the old xylem remain intact. The accumulation of xylem tissues pushes the phloem to the outside, increasing the diameter of the stem. The cells between adjacent vascular bundles form the ***secondary parenchyma*** thus increasing the girth. This increase in diameter of the stem is called ***secondary growth*** or ***secondary thickening***.

In temperate countries, growth of plants is seasonal, only restricted to spring and summer. The secondary xylem appears as a concentric ring which represents one year's growth and is called an ***annual growth ring***. Secondary thickening of the roots also takes place through the activity of the vascular cambium.

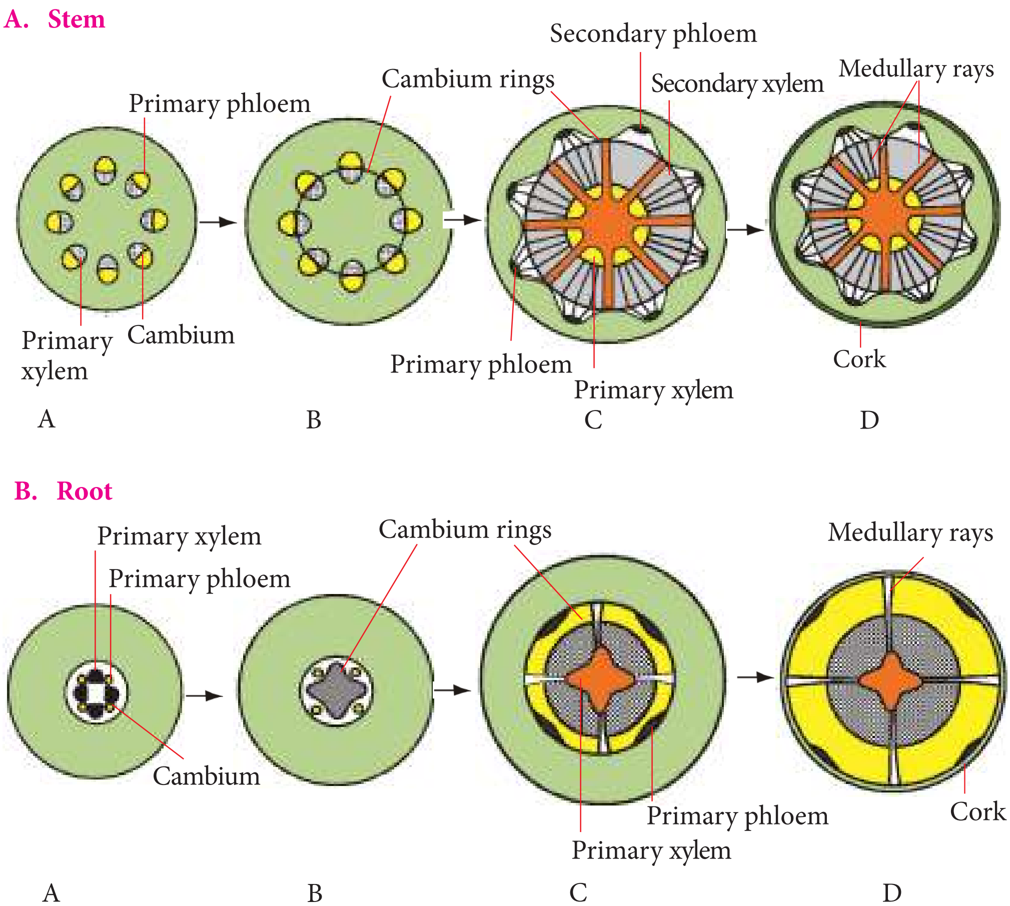


Fig. 2.74: Secondary growth in dicotyledonous stem and root

Apical dominance

Apical dominance refers to the inhibition of the development of the lateral bud by the terminal bud. This is because the apical bud (terminal bud) contains high concentration of the growth hormone called ***Auxin*** or ***Indole Acetic Acid*** (IAA). If the terminal bud is removed, one or more lateral buds develop producing many side branches. The failure of lateral buds to develop in the presence of an apical bud is due to the failure of movement of auxins from the shoot apex downwards.

IAA stimulates the growth of adventitious roots, which develop from the stem rather than the main root. IAA is also involved in the secondary growth causing division of cambium tissue, the ripening of fruit and falling of leaves.

Types of meristems

There are three types of meristems namely apical meristems, lateral meristems and intercalary meristems.

Rate of growth in roots

This is determined by marking the radical of a young germinating seedling using the Indian ink at intervals of 2 mm.

The seedling is then left to grow for sometime (about 24 hours) and the ink marks are examined.

The distance between successive ink marks are measured (Fig 2.75). The results show that growth occurs just behind the tip of the root. The difference between the length of each new interval and the old interval of 2 mm gives the increase in the length of that interval during that period of time. The rate of the growth region can be calculated as follows:

$$\text{Growth} = \frac{\text{Increase in length}}{\text{Original length}} \times 100$$

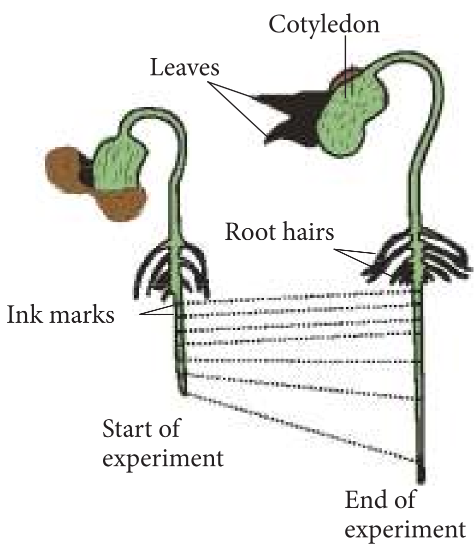


Fig. 2.75: Measurement of root growth in a bean seedling

Table 2.5 below summarises the differences between growth in animals and plants.

Table 2.5: Differences between growth in animals and plants

Growth in animals	Growth in plants
It takes place throughout the body i.e. diffuse growth.	It is restricted to certain regions called meristems i.e. localised growth.
Broken parts such as limbs cannot regenerate.	Broken parts such as branches can be replaced.
Growth involves cell division but not an increase in cell size.	Growth involves cell division, rapid cell elongation and cell differentiation.
Growth is not limited by temperature.	Growth is influenced by environmental factors such as temperature.
Growth leads to a compact shape	Growth leads to a branched shape.

Activity 2.36: Investigating the region of growth in plants

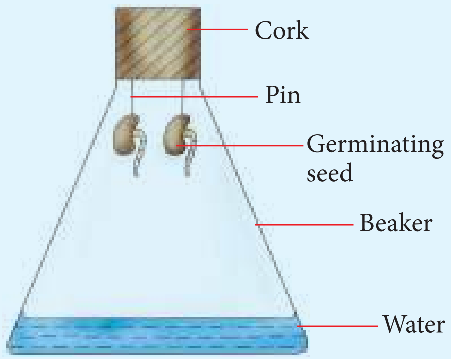
Work as a group

Materials

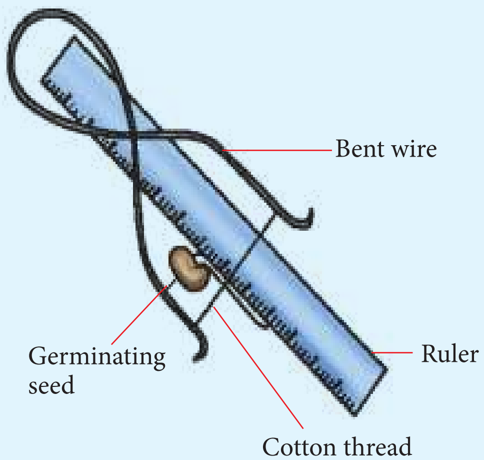
- Germinating bean seeds with a radicle of 1 cm in length
- Cork
- Pin
- Beaker or gas jar
- Water
- Indian ink
- Blotting paper or filter paper and a marker

Procedure

1. Take the germinating bean seeds and dry the radicle carefully using a blotting paper.
2. Make light ink marks 2 mm apart using a marker and ruler along a whole length of a root as shown below.



3. Pin the seedling on the cork and place it in the beaker containing little water as shown in the figure above. Leave it overnight.
4. Take out the seedling and examine the ink marks. Measure the distance between the successful ink marks.



Study questions

1. What part of the radicle has the ink marks moved further apart? Explain your answer.
2. What is the increase in length within each interval?
3. Calculate the rate of growth for the root.

Activity 2.37: Measuring the growth of seedlings

Work as a group

Materials

- Some seeds
- Tins
- Soil
- Water

Procedure

1. Sow some seeds in tins with soil or prepare a place outside the laboratory.
2. Water the seeds regularly until they germinate.
3. Measure the length of the shoot from the soil level to the first leaf and do so with three similar seedlings of the same type and at the same stage of development. Work out the average length.
4. Repeat the above procedure every two or three days for about three weeks.
5. Record your findings in a table.

Study questions

1. Plot the results on a graph paper. Plot the age of the seedling in days on the X-axis against the average length of the seedling on the vertical Y-axis.
2. What do you learn from the graph about the growth of the shoot?

Check your progress 2.20

1. Distinguish between:
   (a) Epigeal and hypogeal germination.
   (b) Primary and secondary growth.
   (c) Radicle and plumule.
2. State the role of the following environmental factors in germination.
   (a) Suitable temperature
   (b) Oxygen
   (c) Water
   (d) Enzymes
3. Outline possible reasons for failure of seeds to germinate after planting.
4. What is the role of the root cap?

Unit 3

Co-ordination in plants and animals

Learning outcomes

Knowledge and understanding	Skills	Attitude
• Understand how coordination takes place in plants and animals.	• Investigate chemical co-ordination in plants. • Investigate the structure of the nervous system in vertebrates to understand sensory, integrative and motor functions. • Develop hypothesis and design investigations on effects of auxins on plant growth.	• Value the importance of plant hormones in plant growth -hence the fruit and vegetables. • Appreciate the commercial application of some plant hormones such as auxin.

Introduction

When you see a fierce dog charging at you, what do you do? Why and how? Similarly, when you touch a hot object, you quickly remove your hands from it. Why?

Plants also have such capabilities. For example, look at the plants below.

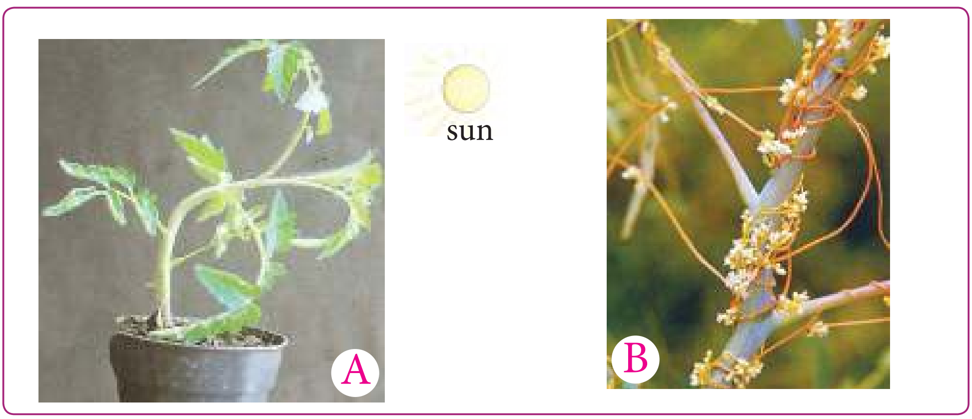


Fig 3.1: Plant responses

What caused the plant in picture **A** to bend? Why? How about the climbing plant in **B**? Why did it wind on the big plant? How do we call these kinds of responses? Do you now have an idea what this topic is about?

When a plant is put in a dark room with an open window, you find that the plant stem grows or bends towards the window where there is a source of light.

Also, some plants with soft stems tend to wind round along sticks, poles and stronger plants in the forests. These two are examples of plant responses. Which other plant responses do you know?

Have you ever wondered why all these responses happen? The reason behind this will be explained in this unit.

3.1 Co-ordination in plants

Living organisms are able to respond to both internal and external stimuli. **Co-ordination** is the process whereby living organism give the correct response at the correct time to a particular stimulus. This allows the organism to adapt, to change and increase their chance of survival.

Plants perceive stimuli that are important to their survival in the environment. The various external stimuli that plants respond to include light, water, gravity, chemicals, temperature and contact.

Plants respond to these stimuli by growing or moving towards or away from their direction. Plant responses that involve growth are called **tropisms**. Those responses that involve movement are called **taxis**. If the response is towards the stimulus, it is a positive response. If it is away from the stimulus, it is a negative response.

The specific responses of plants to a variety of stimuli are as given in Table 3.1.

Table 3.1: Plant responses and their stimuli

Tropisms	Stimuli
Phototropism	Light
Hydrotropism	Water
Geotropism	Gravity
Thigmotropism	Touch
Aerotropism	Air

Note: Geotropism is also referred to as gravitropism.

Activity 3.1: Investigating gravitropism and phototropism

Work as a group

1. You are provided with the following materials:
   - Potted plant seedlings
   - Cotton wool
   - Pea and bean seeds
   - Containers
   - Pins
   - Clamps
2. Design an experiment to investigate gravitropism and phototropism.

Study questions

1. What form of responses is shown by plant shoot and root systems?
2. Explain the roles played by the responses in the life of a plant.
3. What are the other forms of plant responses and their importance to plants?

The facts

Tropisms are directional movement responses that occur in response to a directional stimulus. Plants are not able to relocate if they happen to start growing where conditions are not optimal. However, plants can alter their growth so they can grow into more favourable conditions. To do so requires the ability to detect where the conditions are better and then alter their growth so they can "move" in the appropriate direction. Tropic responses result from differential growth.

Types of plant responses include:

a) Phototropism

Light is a stimulus that plants respond to. This is called phototropism (photo-light). Plants usually display a positive phototropic response to light, which means they grow towards a light source. The elongation on one side causes the plant to bend in the direction of the light. This bending allows more light to reach more cells on the plant that are responsible for conducting photosynthesis.

Fig 3.2: Phototropism

b) Geotropism

The growth response of the radicle and plumule of the seedlings in response to the downward pull of gravity is referred to as geotropism or gravitropism. The response of the radicle to gravity is therefore said to be positive geotropism, and that of the plumule to be negative geotropism.

Gravitropism enables:

- Plant roots to grow downwards in the soil. In this way, roots are able to absorb water and mineral salts for the synthesis of their food.
- Plants to anchor well into the soil hence ensuring that the plant remains firm against possible physical destruction by wind.
- The shoot to grow upwards and as such, leaves are in a position to get light which plants require to carry out photosynthesis.

Fig 3.3: Geotropism

c) Hydrotropism

This is the growth movement towards unidirectional stimuli of water. Roots show positive hydrotropism and shoots show negative hydrotropism.

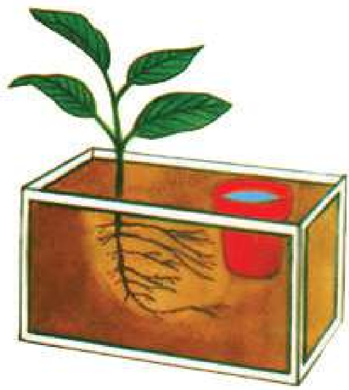


Fig 3.4: Hydrotropism

d) Thigmotropism (haptotropism)

Thigmotropism is a movement or response that is generated when an organism is stimulated by touch. This type of stimulus is known as a **contact stimulus** and is important for the growth and development of many organisms. It is shown mostly by climbing plants, e.g. pumpkins, which have tendrils for support. Root tips grow away from stones and hard surfaces, therefore showing negative thigmotropism.

Fig 3.5: Thigmotropism

Chemotropism: This is the growth movement of part of a plant in response to a unidirectional source of chemicals. For example, pollen tubules grow towards the micropyle in the ovary of a flower where chemicals are produced; therefore the pollen tube is said to be positively chemotropic.

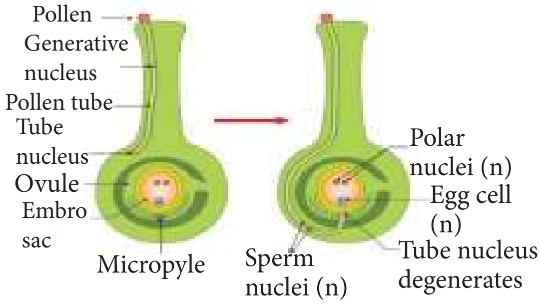


Fig 3.6: Chemotropism

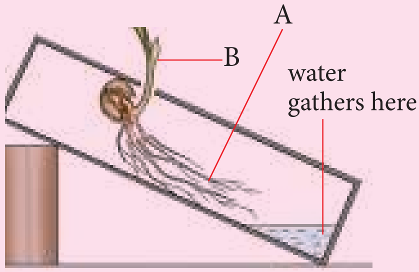
Photoperiodism: This is a situation whereby the plant is sensitive to light durations. Plants use this response during flowering.

Fig 3.7: Photoperiodism

Check your progress 3.1

1. While animals can change their location as a response to a stimulus, plants change their growth pattern. True or false?

2. The diagram below shows a young plant growing in a tilted seed box.



(a) Name the growth response shown by A.

(b) Name the growth response shown by B.

(c) Suggest the benefit to the plant of the growth response shown by B.

(d) Give an example of a regulator in plants that inhibits growth.

(e) Give **two** uses of plant growth regulators in horticulture.

3.2 Role of auxin in controlling shoot growth

Activity 3.2: Research Activity

Work in pairs

The teacher will provide you with textbooks, charts, photographs and videos. You may also use this internet link https://www.youtube.com/watch?v=v93g_g5r3Cw

1. Watch videos provided to you by your teacher and note down observations.
2. Research on the role of auxins. Share your findings with other class members.

The facts

Plant growth and development is influenced by growth regulating substances known as **plant growth hormones**. The hormones are produced in one part of the plant and transported to another part where they influence an aspect of growth. There are five major groups of plant hormones. These are **auxins**, **gibberelins**, **cytokinins**, **abscisic acid** and **ethylene**. In this subtopic, you will learn how auxins influence tropic growth responses.

1. Auxins

Auxins are produced at shoot tips and root tips. They then diffuse away from the shoot tips and root tips influencing cell division and elongation as they move. The amount of auxin present (concentration) affects how the shoot and root grows.

Auxins (**Indole Acetic Acid-IAA**) are plant hormones which control growth. They influence growth by:

- Making the cells permeable to useful substance for growth.
- Increasing the metabolic rate of cells to produce more energy.
- Increasing the turgidity of cells.

Effects of auxin concentration on growth at shoots

In an experiment, the shoot tip of a seedling was cut off. After some time, it was observed that growth had stopped.

When the tip was replaced by an agar block which had been in contact with the cut off tip, growth started again.

When the shoot tip was chopped and the agar block placed halfway the cut off end, the shoot bend towards the side without the agar block.

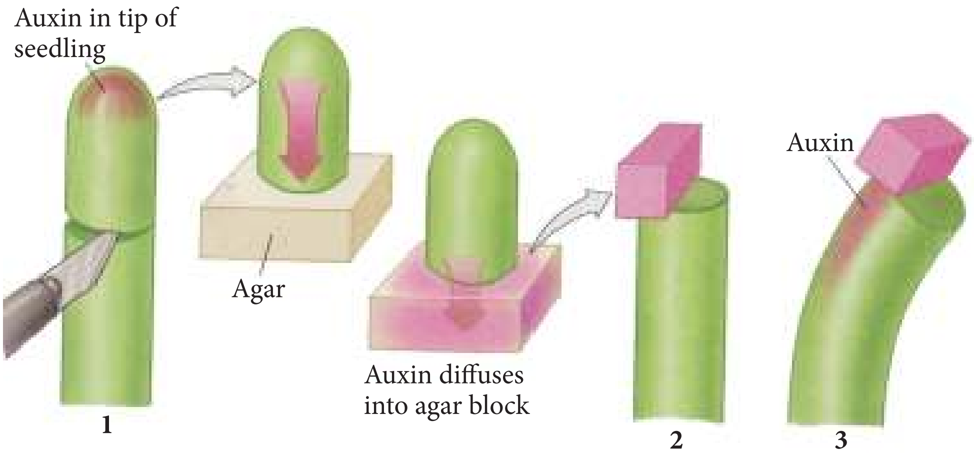


Fig 3.8: Effect of auxins in plant shoot.

This experiment shows that bending of the shoot is caused by an unequal distribution of auxins.

Auxins have strong effects on growth and are therefore required in very small amounts. The concentration that stimulates growth in shoots is higher than the concentration that stimulates growth in the roots. These concentrations occur in different ranges for the shoots and the roots.

The range for the shoot is higher than the range for the root. If the auxin concentration is above or below these ranges, growth is inhibited.

In the shoot tip, the higher the auxin concentration, the more the growth. The lower the auxin concentration, the less the growth. However, in roots, the higher the auxin concentration the less the growth. The lower the auxin concentration within the range, the more the growth. The above-mentioned effects can be illustrated as shown below.

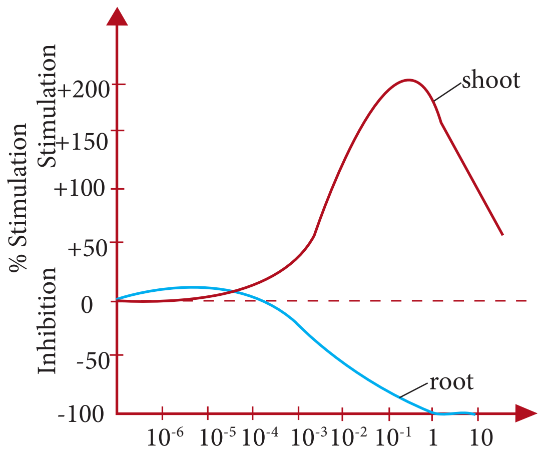


Fig 3.9: Effect of auxin concentration on growth of shoot and root.

Auxins influence cell elongation by causing the cell wall to stretch. As the cells assimilate substances, the cell walls stretch. This increases the length and the thickness of the cell thus increasing the size of the tissue involved. Auxins are involved in plant response towards light, gravity and contact.

Auxins and phototropism

A plant shoot always grows upright because auxins produced at the tip migrate uniformly down the shoot. As a result, they cause all the cells at the zone of cell elongation to elongate uniformly. This leads to uniform growth of the shoot. The shoot will only grow this way under light coming from all directions or under total darkness. This growth occurs as shown in Fig. 3.10 below.

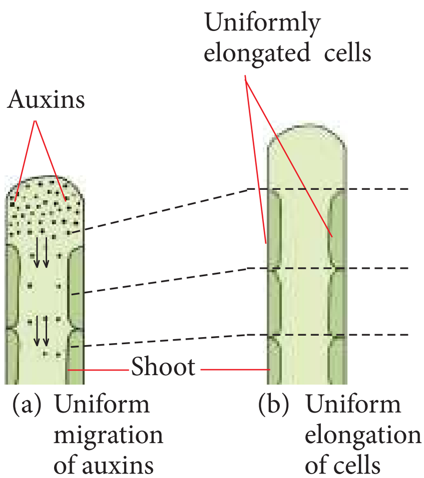


Fig 3.10: Growth of shoot under light coming from all directions or total darkness

Auxins are **sensitive** to light. They usually move away from light. If a plant shoot is exposed to light coming from one direction or unidirectional light, auxins on that side of the shoot of the plant move to the side not exposed to light. The unidirectional light becomes the stimulus. Therefore, the side of the shoot exposed to the unidirectional light has lower concentration of auxins than the side exposed to the unidirectional light. This is as shown in Fig. 3.11.

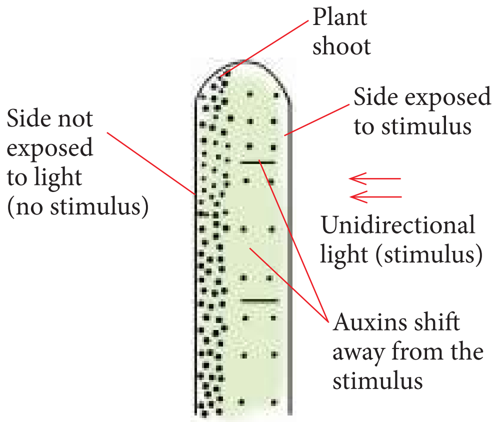


Fig 3.11: Auxins shift to the darker side of shoot away from side exposed to unidirectional light.

The higher concentration of auxins on the side not exposed to the unidirectional light cause cells on that side to elongate more than the cells on the side exposed to the unidirectional light. The side exposed to the light therefore grows less, whereas the side not exposed to the light grows more.

This results in growth curvature of the shoot towards the light as shown in Fig 3.12. This growth response is referred to as **phototropism**.

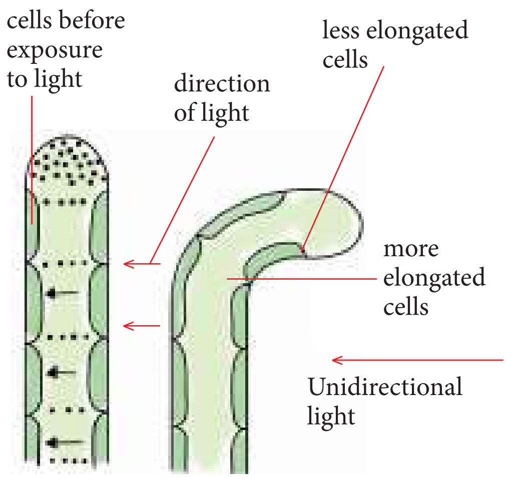


Fig 3.12: More growth of cells on darker side leads to bending of shoot towards the direction of light.

The following are types of tropisms named according to stimuli. They may be positive or negative depending on direction taken. If the growth is directly towards the stimuli then it is positive and if the growth is directly away from the stimuli then it is negative.

Auxins and geotropism

Geotropism is a response of plants to the stimulus of the pull of **gravity**. The roots show positive geotropism while the shoot shows negative geotropism. Under normal circumstances, the shoot plumule grows upwards and the root grows downward.

If a seedling was growing horizontally, the radicle grows bending downwards while the plumule grows bending upwards. This is because as auxins are produced, they diffuse away from the tip. The force of gravity pulls the auxins downwards. These cause auxins to concentrate along the lower part of the radicle and plumule as shown in Fig. 3.13 below while the upper side of the radicle and plumule end up with a lower concentration of auxins.

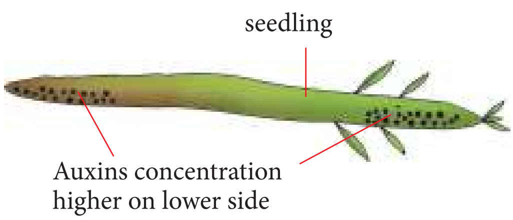


Fig 3.13: Seedling with auxin concentrated more on the lower side

In the **plumule** (young shoot), the lower part has a higher auxin concentration. The cells here elongate more. This results to more growth. The upper part has lower auxin concentration. The cells here undergo less elongation. This results to less growth. As a result, the plumule grows curving upwards. This is negative geotropism.

In the **radicle** (young root), the lower part has a higher auxin concentration. The cells here undergo less elongation. This causes less growth. The upper part has a lower auxin concentration. The cells here elongate more. This causes more growth. As a result, the radicle grows curving downwards. This is positive geotropism.

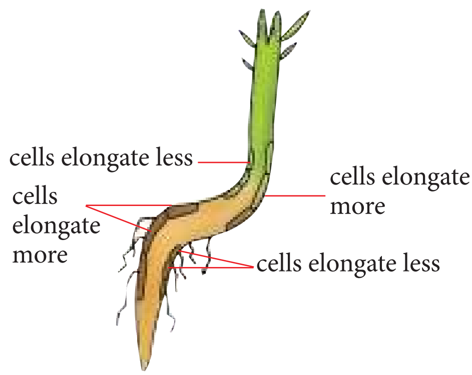


Fig 3.14: Geotropism as explained by distribution of auxins due to gravity

Auxins and thigmotropism

The growth response of plants towards the stimulus of **contact** coming from one direction is referred to as thigmotropism.

This response is also controlled by auxins. The contact influences the migration of auxins away from it. As a result, the side of the seedling in contact has less auxins. Cells on this side undergo less elongation. This causes less growth. The side further away from the point of contact has a higher concentration of auxins. As a result, the parts in contact with the supporting structure grow curving towards the point of contact. This way, the plant grows twining along the supporting structure.

Use of auxins as weed killers

Plant chemical hormones that work like plant hormones can be used to control unwanted plants. Auxins and chemicals that act like auxins are used in various types of weed killers. Some of the chemicals that have been used in the past or present include 2,4-D and 2, 4, 5-T.

These herbicides generally mimic auxin, a plant growth hormone. Auxin herbicides stimulate a variety of growth and developmental processes when present at low concentrations at the cellular sites of action. However, with increasing concentration and auxin activity in the tissue, growth is disturbed and the plant is lethally damaged.

The synthetic auxins are used primarily to control broad leaf weeds in grass crops and pastures.

Activity 3.3

Work as a class

Watch a video clip from the following link: *https://www.youtube.com/watch?v=Zu9h7Wf7iBI* or use reference materials such as textbooks to research on different types of plant hormones.

Study questions

1. Which hormone is responsible for ripening of fruits?
2. How does auxin and gibberelins work in plants?
3. How does absicic acid cause falling of leaves in plants? Explain.
4. Illustrate using a well labelled diagram how cytokinin brings about development of lateral buds in plants.

2. Gibberelins

Gibberelins are also a group of plant growth hormones that affect plant growth. The most common one is Gibberrelic acid. They are involved in many activities such as:

(i) Stimulation of flowering in some plants.

(ii) Elongation of internodes.

They influence elongation and expansion of cells after cell division. This causes elongation of stems.

For instance, cabbages which usually have short internodes can be treated with gibberelins at the internodes.

This will cause elongation at the internodes.

(iii) They are used in breaking seed dormancy.

(iv) Promote growth of side branches.

Fig 3.15: Gibberelings stimulate flowering in plants

Fig 3.16: Gibberelings stimulate stem elongation in plants

3. Cytokinins

Cytokinins are plant hormones that promote cell division and growth in seedlings. They are found in small quantities in plants.

i) They stimulate formation of callous tissue that heals damaged tissues in plants.

ii) They also contribute to breaking of seed dormancy in plants, enlargement of cotyledons and development of lateral buds.

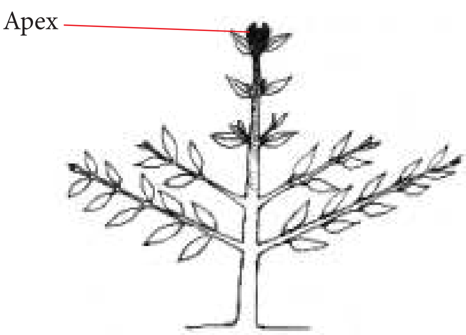


Fig 3.17: The apex of a seedling

iii) They also prevent aging of leaves.

4. Abscisic acid

This is a hormone that influences the shedding of leaves and the slowing down of plant activities during dry seasons. It is mainly found in plant organs such as buds fruits, seeds and tubers and at the bases of leaves.

Abscisic acid causes

(a) Leaf fall

Some plants prepare for seasons of low water availability and high temperatures. When the trees shed their leaves, this helps the plants conserve water.

Fig 3.18: Abscisic acid causes falling of leaves

(b) They contribute to seed dormancy.

5. Ethene (Ethylene)

Ethene is available as a gas. It speeds up fruit ripening. It is produced by flowers' outer leaves and covering of the fruit. Ethene can also promote leaf fall. Fruit growers use it to influence ripening of fruits to suit their market demands. In absence of ethylene, fruits take long to ripen. With a lot of ethylene, fruits ripen very fast.

Fig 3.19: Effect of ethylene on plant flowers and leaves

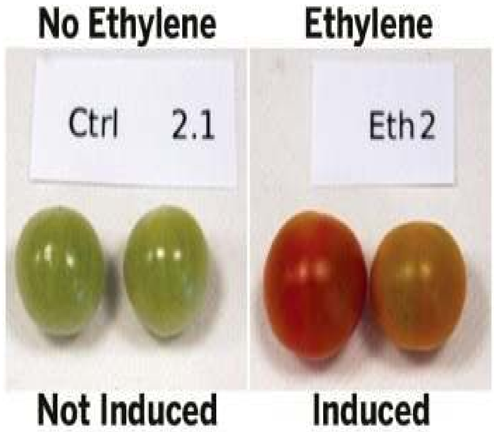


Fig 3.20: Ethylene on fruits

Check your progress 3.2

1. Explain the behaviour of auxins when a shoot tip comes into contact with an object.
2. When you prune your plants you remove _____ that was produced by the apical meristem so your plants spread out.
3. Auxins promote growth at a very low concentration in _________.

   A. shoots B. roots C. flowers D. nodes
4. The table below shows the effects of auxin at different concentrations on the growth of shoots and roots of oat seedlings. The elongation of the test seedlings was compared to the elongation of a group of control seedlings which did not receive auxin treatment. A positive value indicates that the test seedlings grew more than the controls and a negative value indicates that the test seedlings grew less than the controls.

Auxin concentration / parts per million	Elongation relative to control/mm	
	Shoot	Root
10-6	0	+3
10-5	0	+5
10-4	+2	+11
10-3	+6	+10
10-2	+9	-3
10-1	+34	-23
1	60	-38
10	+33	-40
100	-22	-40

a) Plot these results in a suitable graphical form.

b) Compare the response of the shoots to auxin with the response of the roots.

c) Synthetic auxins are used as weed killers. Suggest how they operate selectively to kill broad leaved weeds such as plantains in a lawn.

3.3 Other forms of plant responses

Activity 3.4: Research activity

Work in groups

Your teacher will provide pictures and videos of other forms of plant responses.

1. Observe and note the different forms of plant responses.
2. Write a report of your findings and present it in class.

The facts

Nastic response is a non-directional movement of part of a plant in response to an external stimulus. It mainly depends on the intensity of the stimulus.

Nastic movements are generally caused by changes in the osmotic pressure due to an influx or efflux of ions that cause water to move in or out of the cells. In many plants, shrinkage of the motor cells causes the overall movement of the plant.

Nastic movements in plants are reversible and repeatable movements in response to a stimulus whose direction is determined by the anatomy of the plant. They are generally slow movements. Examples include:

i. The leaves of many plants respond to the daily alternation between light and darkness by moving up and down. Leguminous plants exhibiting nastic movements include the sensitive plant *Mimosa pudica* shown in Fig. 3.21 and the silk tree.

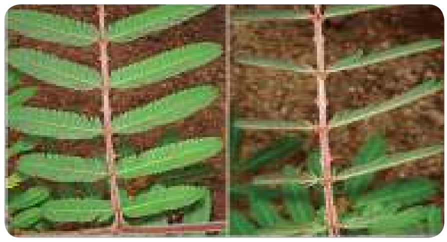


Fig 3.21: Mimosa plant before and after touch

ii. Mechanical disturbances that may trigger movements include touch or shaking the plant. The leaves of carnivorous plants such as Venus fly trap respond in a rapid, highly specialised way when an insect touches their leaves. The leaves have two lobes, within about a half-second, the two lobes of the leaf shut. Enzymes digest the insect in one to several days and the empty trap then reopens.

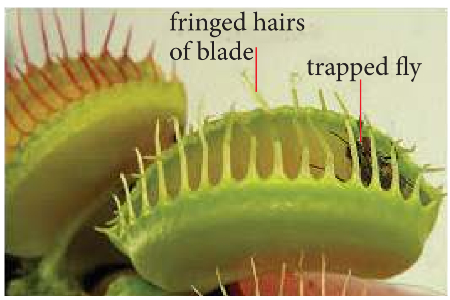


Fig 3.22: Venus fly trap showing leaf shut after trapping insect

iii. Movements of developing buds which swell, open up and eventually fall off.

iv. The opening and closing movements of many flowers,

v. The responses of leaves to changes of temperature and light.

Table 3.2: Differences between tropism and nastic responses

Tropism	Nastic
The direction of movement is determined by the position of the origin of the stimulus.	The direction of movement is determined by the anatomy of the plant.
The movement is in a direction either toward or away from the origin of the stimulus.	The movement is determined by the position of the origin of the stimulus.
Changes that occur are generally irreversible.	Changes that occur are temporary; they are reversible and repeatable.

Check your progress 3.3

1. The figure below shows a *Mimosa pudica* plant responding towards touch.

a) Identify the type of plant response shown above.

b) Why do the leaflets fold immediately after being touched? Explain.

c) Give three reasons why the above response is important to the plant.

2. The leaflets of *Mimosa pudica* fold when ______ ions move out of the cells.

a) Potassium

b) Calcium

c) Magnesium

d) Chlorine

3.4 Co-ordination in animals

When you write in your book, your eyes help in locating the space to write in. The skin on your hand feels the page and the brain interprets what you are writing. All these activities occur in a coordinated manner. Look at the following diagram.

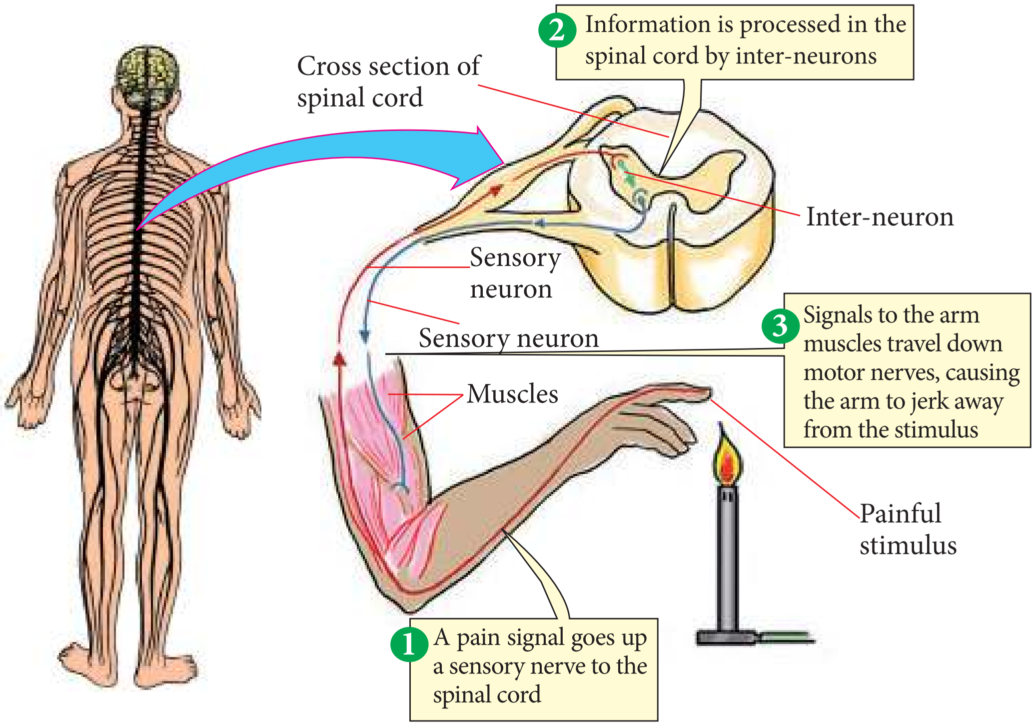


Fig 3.23: Signal transmission and response

It shows what happens when you touch hot objects or fire. Study it carefully. Try to understand the relationship between the spinal cord, the hand muscles and the skin on the finger. Trace the path of the stimulus from when the fire is detected at the finger until when it is removed. What does this tell you about how our bodies work?

Activity 3.5: Discussion Activity

Work in groups

1. Discuss in your groups why organisms require coordination and response.
2. Using textbooks provided by your teacher, look at the meaning of the following terms:
   - Coordination
   - Irritability
   - Stimulus
   - Response
   - Receptors
   - Effectors

   You can also use the internet
3. Share your findings with the rest of the class.

The facts

Sensitivity is one of the characteristics of living things. It is the ability of an organism to sense or detect changes in the environment and respond to them. Living organisms have the ability to detect changes in their internal and external environments. They respond to these changes appropriately.
This characteristic is of great survival value to the organisms. The structures involved in detecting the changes may be located far away from the ones that respond. Therefore, there is need for communication pathways within the body to link the structures involved in detecting changes with the structures that respond to the changes.

In animals, coordination is performed by the nervous system and the endocrine system as you will learn in this unit.

Animals, like plants, are able to perceive changes in their external and internal environment. They detect these changes through special cells and organs called **receptors**. The process of detection or perceiving the changes is known as **reception**.

They then respond appropriately to enhance their survival. Muscles and glands that bring about responses are referred to as **effectors**. The receptors and effectors are linked together by a coordinating system composed of the **nervous system** and the **endocrine system**. The endocrine system is made up of ductless glands which release hormones.

Check your progress 3.4

1. Why is the control and coordination system necessary in organisms?
2. What are the two control and coordination mechanisms developed in animals?
3. What are the units of nervous system?
4. Describe how conduction of messages take place in the following:
   (i) Nervous system
   (ii) Endocrine system

3.5 Structure of the nervous system in vertebrates

Carry out Activity 3.6 to investigate the components of the human nervous system.

Activity 3.6: Investigating the components of the human nervous system

Work in groups

Materials

- Charts
- Models of different parts of the human nervous system

Procedure

1. Observe the charts and models presented.
   - What are the components of the human nervous system?

- Can you name and label the different parts of the nervous system?
- Suggest functions of the different parts of the nervous system.
- How do the parts above work together?

2. Draw the parts observed in your notebooks.
3. Present your findings to the class.

The facts

The nervous system is a system of specialised cells known as **nerve cells** which are linked to each other and to different sensory cells and effectors in the body.

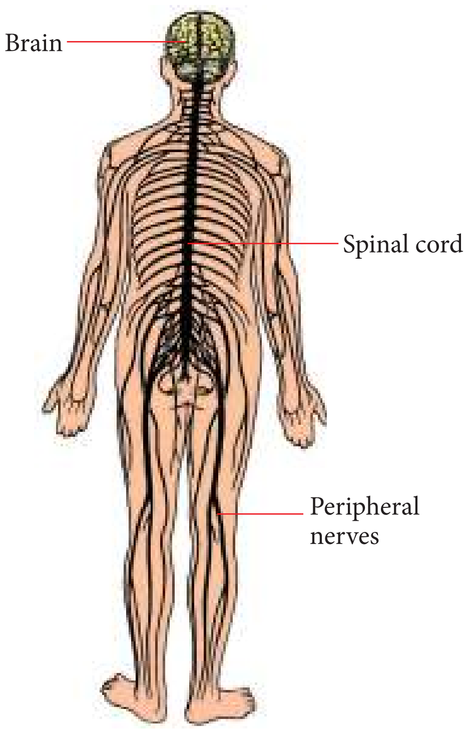


Fig 3.24: Parts of the human nervous system

The nervous system is composed of the following:

- The central nervous system (CNS) which is made up of the brain and the spinal cord.
- The peripheral nervous system - which is made up of the peripheral nerves.

The central nervous system

The central nervous system is made up of the **brain** and the **spinal cord**. The spinal cord is an extension of the brain.

The brain

The brain is protected by three main structures.

(i) The skull (cranium) – which protects it externally.
(ii) The meninges – these are membranes which protect it internally.
(iii) Cerebral–spinal fluid - this is a shock absorber and it also provides nourishment to the brain.

The brain is composed of three regions namely:

1. The fore brain (Cerebrum and olfactory lobes).
2. The mid brain (Hypothalamus, optic lobes, thalamus and pituitary gland).
3. The hind brain (Cerebellum and Medulla oblongata).

The brain functions to:

- Receive impulses from sensory organs and send them to the respective organs for proper functioning of the body (relay centre).

- Make decisions based on inherited characteristics or past experiences so as to modify behaviour.
- Help the muscular body balance.
- Co-ordinate the vital body processes like regulation of body temperature, breathing and heartbeat.

The brain is made of two halves known as **hemispheres.** These are the **right hemisphere** and the **left hemisphere.** The two hemispheres are interconnected by a group of nerves called **corpus callosum.** The hemispheres are organised into a number of parts. These include cerebrum, cerebellum, medulla oblongata, hypothalamus, thalamus, pons and pituitary bodies. The right hemisphere controls activities of the left side of the body while the left hemisphere controls activities of the right side of the body. The outermost part of the brain is called the **grey matter.** Beneath the grey matter is an inner larger part known as the **white matter.**

The brain is covered by three membranes known as **meninges.**

- The outer membrane is tough and delicate and is known as the **dura matter.** This membrane protects the brain from mechanical damage.
- The inner membrane is known as the **pia matter.** It is composed of blood capillaries and lymph vessels.
- **Arachnoid matter** is the middle layer of the meninges. It is filled with cerebral-spinal fluid. All blood vessels entering the brain pass through this space. The fluid distributes oxygen and nutrients to the nervous tissues. It also helps to protect the central nervous system against mechanical shock because of its cushioning effect. The fluid contains lymphocytes which also protect the brain against disease infections.

Parts of the brain and their functions

The brain is divided into two hemispheres, the left and the right hemispheres. Fig. 3.25 below shows the structure of the brain.

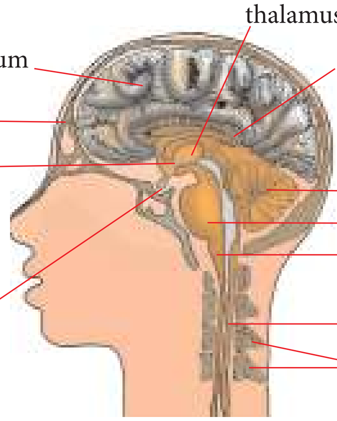


Fig 3.25: Section through head to show the brain

Cerebrum

The outer layer of the cerebrum is called **cerebral cortex**. It has many folds on its outer layer. These folds increase the surface area and hence a higher number of neurones.

When you are practicing for your music and drama festivals, you probably recite poems and act in plays.

- *What do these activities involve?*

These activities probably involve reading and remembering lines and verses, creating interesting costumes, understanding difficult themes in the play, having confidence to make presentations, learning and coordinating dance steps among other things.

When you are carrying out all these activities, the part of your brain that is involved is the cerebrum.

Cerebrum is the largest part of the human brain. It makes up about two-thirds of the brain.

Did you know?

Cerebrum is divided into the right cerebral hemisphere and the left cerebral hemisphere.

The cerebrum therefore has the following functions:

- It is the thinking centre.
- It is involved in imagination and creativity.
- It is the memory centre.
- It is the intelligence centre.
- It is responsible for personality or character.
- It is responsible for emotions such as joy and sorrow.
- It is involved in voluntary control of body movements such as walking, dancing and jumping.
- It receives and interprets (sorts out) impulses from the sense receptors. These receptors include the eyes, ears, taste buds and nose and receptors for touch, pain, pressure, heat and cold receptors in the skin and other organs. This means that the cerebrum is responsible for sight, hearing, taste, smell and speech.

Health check!

A Plasmodium parasite sometimes can enter the brain and specifically in the cerebrum. This causes cerebral malaria. Cerebral malaria may lead to mental disorder if not treated early. It is therefore important to take malaria patients to hospital as early as symptoms appear to avoid this condition.

Cerebellum

The cerebellum is found below the rear part of the cerebrum. Like the cerebrum, it is divided into two hemispheres; left and right. The cerebellum is smaller in size than the cerebrum. It also has folds on its outer layer that increase surface area and hence a higher number of neurones.

Assume you are watching a final football match between your school and a neighbouring school. The striker of the opposing team dodges the defense of your team and remains with the goalkeeper. Everyone waits for the goal to be scored. Surprisingly, the goal keeper saves it.

- What do you think the goalkeeper had to do to save the ball?

The goalkeeper probably had to keep his or her eyes on the ball to judge the speed and its direction. This way, he or she managed to coordinate his or her movements to dive and catch the ball.

The part of the brain that was involved in this type of coordination is the cerebellum. The functions of the cerebellum are as follows:

- Coordination of body movements.
- Maintaining body balance and posture.
- Ensuring dexterity in fine movements like using hands and fingers to carry out skilful tasks such as playing a guitar, sewing and typing.

Health check!

Sexually transmitted disease known as **syphilis** can affect the nervous system. The disease in its late stages may lead to madness as a result of the **infection of the cerebellum.** It is therefore, important for each one of us to have behaviour change in order to avoid contracting STIs.

Medulla oblongata

The medulla oblongata is located beneath the cerebellum. It is connected to the spinal cord.

Consider a situation whereby you hold your breath for some time.

- How long do you think you can do this?
- What is it that makes you gasp for air even if you intended to continue holding your breath for a longer time?
- Do you gasp for air deliberately or is it something you cannot control?

You gasped for air without your will because you had intended to hold your breath longer. The gasping is a response you could not control. Such a response is referred to as **involuntary action.** If you had not gasped involuntarily, you may have died due to lack of oxygen. Such a response is an example of a vital involuntary action. Such responses are controlled by the medulla oblongata.

The function of the medulla oblongata is to control involuntary responses such as:

- Breathing
- Blood circulation
- Heart beat, digestion and swallowing

Other parts of the brain include:

- **Pons** - Works together with medulla oblongata to bring about involuntary activities.
- **Thalamus** – Relays sensory

information to other parts of the brain.

- **Hypothalamus** – Controls secretion of hormones by pituitary glands and so it is involved in homeostatic processes. It also control hunger, thirst and sleep.
- **Corpus callosum** – Composed of axons that connect the left and right hemispheres.
- **Corpora quadrigemia** – Controls movement of head and trunk and have relay neurones for sight and hearing.
- **Pituitary gland** -This is an endocrine gland responsible for the production of many hormones that control other endocrine glands. It is also known as the **master gland**.

The spinal cord

As we have mentioned, the spinal cord is an extension of the brain. It extends from the base of the brain as shown in Fig. 3.26 below.

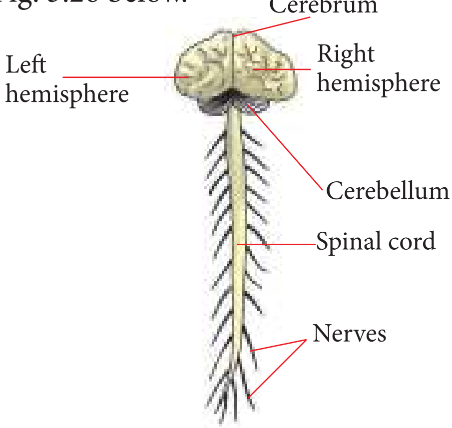


Fig 3.26: The central nervous system

The outer parts of the spinal cord contain the white matter and the inner parts contain the grey matter. There is a narrow canal called the **central canal** which runs down the spinal cord. The canal is filled with the cerebral-spinal fluid. The spinal cord is also covered by the meninges that protects it against mechanical damage.

The functions of the spinal cord include:

(i) Linking the nerves of the peripheral nervous system with the brain.

(ii) Coordinating certain automatic responses.

(iii) Coordinating spinal reflexes.

The peripheral nervous system

This is a system of nerves that connects the spinal cord and the brain to all other parts of the body.

The nerves that connect the brain to the surrounding parts in the head such as the ears and the eyes are known as **cranial nerves.** The nerves that connect the spinal cord to surrounding parts of the body such as hands, legs, ribs and abdomen are known as the **spinal nerves.**

The peripheral nervous system connects the receptors to the central nervous system. It also connects the central nervous system to the effectors. The peripheral nervous system is divided into:

- Voluntary, which is responsible for the movement of the skeletal muscles.

- Autonomic (involuntary) nervous system. This is responsible for the involuntary movements in the body like breathing, heartbeat and movement of food along the gut.

The nervous system carries out the following functions:

- It perceives the changes around us through our senses.
- It controls and coordinates all the activities of the muscles in response to the changes outside.
- It also maintains the internal environment of the body by coordinating the functions of the various internal organs and the involuntary muscles.
- It stores the previous experiences as memory that helps us to think and analyse our reactions.
- It conducts messages between different parts of the body.

Check your progress 3.5

1. CNS refers to which of the following?
   A. The central nervous system consisting of the brain and spinal cord.
   B. The cerebral nervous system consisting of the brain, spinal cord and retinas.
   C. The central nervous system consisting of the brain and motor neurons.
   D. The cerebral nervous system consisting solely of the brain.
2. The ________ contains centres for heartbeat, breathing and blood pressure.
   A. Cerebellum
   B. Cerebrum
   C. Spinal cord
   D. Medulla oblongata
3. This is the job of the nervous system.
   A. To make us think.
   B. To send messages to and from the brain and spinal cord to and from the body.
   C. To break down food to be used by the body.
   D. To remove wastes from the body.

3.6 Structure and functions of neurones

Suppose your finger is pricked by a needle. You have felt the sensation. Then your brain senses the prick and generates a response and you withdraw your hand. This flow of message through the nerve is called **impulse**.

Nerve impulse upon generation passes along a neuron in only one direction. The neuron is connected to a sensory receptor that receives the message or stimulus and converts it into electrochemical waves. These electrochemical waves are carried by the neuron. The stimulus from the receptor organ is received by the dendrites, conducted to the cell body of the neuron and finally to the effector organ.

Activity 3.7: Observing the structures of neurones

Work in groups

Materials

- Textbook
- Manila paper
- Labels
- Clay
- String or piece of wire
- Scissors

Procedure

1. Research on different types of neurones.
2. Design models of different types of neurons using the materials provided and stick on a manila paper.
3. Allow it to dry and present in class.
4. Carry out a presentation in class highlighting the similarities and differences observed between the neurons and their functions.

The facts

The nervous system is made of specialised cells known as **nerve cells**. The nerve cells are also referred to as **neurones.** The neurons relay an electrical signal called a **nerve impulse**.

A typical neurone consists of a cell body, which gives rise to a number of extensions. These extensions can further branch at their ends. One extension which is longer than the rest is called the **axon**. The axon transmits messages away from the cell body. The other extensions are called **dendrons**. They carry messages towards the cell body. Sometimes, other extensions may branch from the dendrons.

The extension that branch from the dendrons are known as **dendrites.** An axon may be very long. It can, for example, connect the spinal cord to the big toe. The axon may be surrounded by a sheath of fatty substance called the **myelin sheath.** The axon and the sheath together make a **nerve fibre.**

Several nerve fibres put together form a bundle which is referred to as a **nerve.**

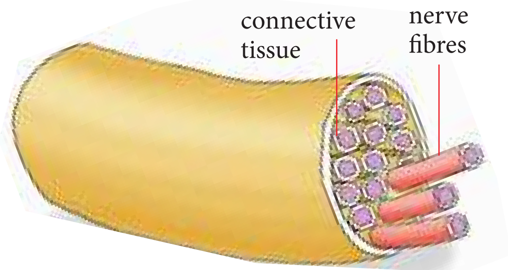


Fig 3.27: Nerve fibres grouped together forms a nerve.

The myelin sheath acts as an insulating material. At certain points along the length of the axon, the myelin sheath is constricted. The constrictions form junctions called **nodes of ranvier.** The nodes of ranvier together with the myelin sheath increase the speed of transmission of impulses. This myelin sheath is formed by cells called **schwann cells.** The schwann cells occur in the outer region of the sheath along the nerve cell (neurone).

There are three main types of neurones. These are:

- **Sensory neurons**, which transmit impulse from receptor (sense organ) to the central nervous system (brain or spinal cord).
- **Motor neurons**, which transmit impulse from central nervous system to effectors (muscle or glands).
- **Intermediate neurons**, which connect sensory and motor neurons, found in the grey matter.

The three types of neurons vary in structure. However, they share a number of structural features and these include:

1. Cell body

This consists of dense cytoplasm surrounding a prominent nucleus. It is where energy required to transmit the impulse is produced and the nucleus controls all the other activities within the neurone. In motor neurons, the cell body is found at the end of axon and it branches into dendrones which also branch into dendrites.

2. Myelin sheath

This is a fatty material that surrounds the axon. It is produced by Schwann cells. The myelin sheath insulates and protects the axon and also aids the transmission of impulses. It is broken at various points called **node of Ranvier** and this increases the rate at which the impulse is transmitted.

3. Dendrites

These provide connection in form of a synapse with other neurones to effect communication. They are delicate hair-like out growths which are in close contact with other neurones or with stimulus receptor cells.

4.The axon

This is a long cytoplasmic extension running from the cell body. Inside the axon is exoplasm which contains ions that facilitate transmission of impulses. In motor and sensory nerves, it is usually covered with myelin sheath.

Sensory neurones

This is also called **receptor neurone.** These are neurones that carry messages (impulses) from the sensory cells and organs to the central nervous system. Their cell body are located outside the central nervous system. The cell body gives rise to a nerve fibre that divides into two. The branch which leads to the central nervous system is known as the **axon.** It relays impulses away from the cell body.

The other part of the nerve fibre is called the **dendron.** It relays impulses towards the cell body. There is only one **dendron** and it is longer than the axon.

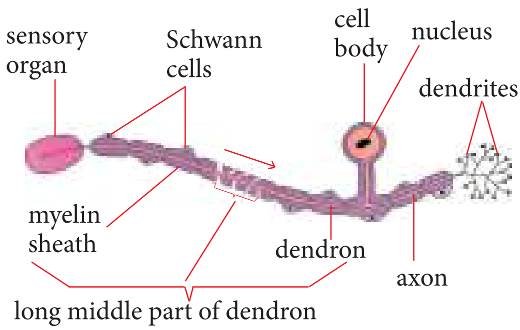


Fig 3.28 Sensory neurone

Motor neurones

These are neurones that carry impulses from the brain and spinal cord to the effectors (muscles and glands). The cell body of a motor neurone is located in the central nervous system.

Its cell body gives rise to a long axon and many dendrons. See Fig. 3.29 below.

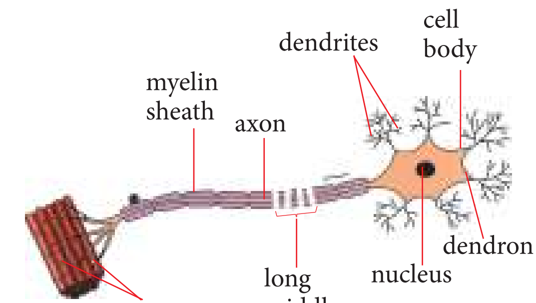


Fig 3.29: Motor neurone

Intermediate neurone

These are neurones that relay impulses from the sensory neurones to the motor neurones. They are therefore sometimes known as **relay** neurones. These neurones are wholly located in the grey matter of the brain and the spinal cord. They have relatively short axons.

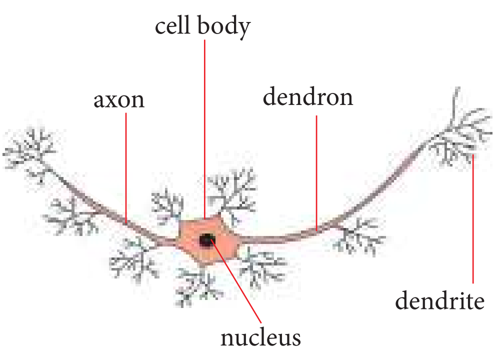


Fig 3.30: Intermediate (relay) neurone

Activity 3.8

Work in pairs

Materials

- Ruler
- Pen

Procedure

1. Let your partner place a ruler or a pen close to the edge of the desk or a table.
2. Assume you were doing something else and your friend signals you to catch the ruler or pen using your fingers so that it does not fall down.
3. How will you respond to prevent the ruler or pen from falling down?
4. Why is this so? Explain.
5. Change roles and repeat the activity again.

Synapses

A synapse is a specific functional point that links one neuron to another or it is a means by which a nervous impulse is passed from one neuron to another.

Impulse transmission across a synapse

When a stimulus reaches the receptors, it generates an impulse which passes to the cell body of the sensory neuron. The impulse then goes through the axon to the dendrite and then to the dendrite of another neuron across the synapse.

An impulse in one axon triggers release of a transmitter substance (acetylcholine) into the synaptic gap.

The transmitter substance stimulates the adjacent neurone to form an impulse and so the stimulus is passed on.

The transmitter substance is then destroyed and is resynthesised to carry more impulses. This ensures that an impulse travels only in one direction.

Check your progress 3.6

1. A neurone generally has all of the following principle areas except ________.
   A. microvilli
   B. a cell body
   C. dendrites
   D. an axon
2. ______ send signals away from neurons whereas ______ receive signals from other neurons.
   A. Dendrites; axons
   B. Axons; dendrites
   C. Axons; synapses
   D. Synapses; dendrites
3. Which items should not be grouped together?
   A. Spinal nerve
   B. Cranial nerve
   C. Spinal cord
   D. PNS

3.7 Reflex arcs and reflex actions

Assume you climb a mango tree to pick a mango fruit. As you reach out for one big, ripe and juicy looking mango, you suddenly spot a snake moving towards the mango.

- What do you think you would do?

You would probably quickly withdraw your hand and jump down the tree and run away very fast without thinking.

- What would you call such a response?

Activity 3.9: The knee jerk experiment

Work in pairs

1. Ask your partner to sit on a chair with their legs crossed so that one leg hangs freely.
2. Strike sharply the part just below the knee of the hanging leg using a ruler or edge of your hand.
3. Make your observations.
4. Change places with your partner and repeat the activity.

Study questions

1. What did you observe when you struck your partner's knee?
2. What type of response is this?

The facts

You may have noted that the knee kicked or jerked. This sudden response is automatic and is not under the conscious control of the individual involved. It is an example of a reflex action. It is called a knee jerk action.

A **reflex action** can be defined as a rapid and automatic response to a stimulus. It usually has a survival value. They are involuntary, for example, your behaviour in the cited case involved several actions that helped you escape from the snake and avoid being bitten.

- Suggest examples of some other reflex actions you may know and their possible survival values.

Reflex arc is described as the path taken by a nerve impulse in a reflex action. The route that is followed by impulses during a reflex action is called **reflex arc**. A reflex action moves in the following direction:

1. A receptor is stimulated and an impulse travels along a sensory nerve fibre to the spinal cord.
2. The impulse is picked up by an intermediate neuron within the CNS.
3. The intermediate nerve fibre transmits the impulse to a motor nerve fibre which is connected to an effector.
4. The effectors which could be muscles or glands respond to the stimuli appropriately.

Spinal reflex: This is a reflex action which involves the spinal cord. It usually occurs in actions which occur below the head such as knee jerk and peristalsis.

Cranial reflex: This is a reflex action which occurs in the region of the head and it involves the brain, for example salivation and blinking.

Characteristics of reflex actions

- They occur rapidly.
- They occur spontaneously and take a short time.
- They are coordinated either by brain or spinal cord.
- They are not learned but inborn.

There are two types of reflex actions:

- Simple reflex action.
- Conditioned reflex action.

(a) Simple reflex action

Have you experienced any of the following?

(i) Touching a hot object, you quickly withdraw your hand. This prevents burning of the hand.

(ii) Sudden blinking when someone throws an object towards your eyes. This prevents the eye from possible physical injury.

(iii) Salivation at the sight of food. This prepares the individual for softening and lubrication of food to make it easy to swallow.

(iv) Sneezing when dust gets into your nose. This helps in releasing and expelling the dust that may contain infectious bacteria.

(v) Constriction of the pupil of the eye in response to light intensity. This prevents excessive entry of light into the eye which can damage cells in the retina of the eye.

(vi) Secretion of tears when an onion is peeled near you. The tears wash away the irritating chemicals that can damage the eye.

All the above are examples of simple reflex action: a given stimulus always produces the natural or expected reflex response.

During a simple reflex action, an impulse passes through a certain pathway from the receptor to the effector. This pathway usually involves the three neurons; the sensory neurone, the intermediate neurone and the motor neurone.

The stimulus is detected by receptor cells which form an impulse and transmits it to the sensory neurone. The sensory neurone then transmits the impulse to the intermediate neurones in the central nervous system. The intermediate neurones then transmit the impulse to the motor neurones. The motor neurones then transmits the impulse to the organ which brings about a response to the stimuli. This pathway of stimuli that is responsible for bringing about a reflex action is called a **reflex arc** as illustrated below.

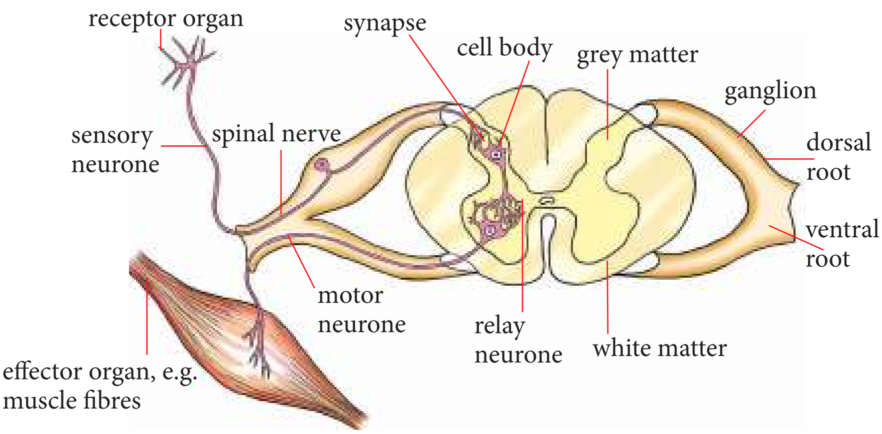


Fig 3.31: The reflex arc

In the nervous system, the ends of adjacent neurones are not in actual contact. There is a very small gap found between them. This small gap is called a **synapse.** It is through this synapse that impulses are transmitted from one neurone to another.

A synapse is a junction formed when two neurones meet end to end.

(b) Conditioned reflex action

Assume your name is Fredrick. You are appointed to be the new captain in your school. You have always responded to the name Fredrick. When the students started calling you captain, you could not readily respond because you were not used to it. When the students realised this, they started calling you 'Captain Fredrick'. They repeatedly used the two names together. As a result, when the name Captain was subsequently used alone, you were able to respond to it.

- Why do you think you are not able to respond to the name 'captain' alone?

At first, the name you were used to was Fredrick and not Captain. You could not respond when called Captain. When the two names were repeatedly used together, you realised that you were the one being referred to. You therefore learnt to associate the name Captain to your name. So, when the name Captain was used alone, you were able to respond. Your ability to respond automatically to the new name captain in the absence of your name Fredrick is an example of a conditioned reflex action.

A **conditioned reflex action** can be defined as an automatic rapid action in response to a stimulus which is substituted for the normal or natural stimulus. This action is also referred to as **learnt response**. It involves response to unrealistic stimulus. For this to be possible, the individual must be exposed to the new stimulus repeatedly over a period of time. This is the process of learning or conditioning.

Other examples of conditioned reflex action include:

- Cycling
- Walking
- Swimming
- Driving
- Training of animals in various skills.
- Can you suggest some other examples of conditioned reflex action apart from the ones given above?

Pavlov's experiments on dogs

Ivan Petrovich Pavlov was a Russian physiologist known primarily for his work in classical conditioning. He discovered that by placing food near a dog's mouth, he could cause the dog to secrete saliva. He rang a bell at the same time for several days as he gave the dog its food. Finally, he rang the bell without giving the dog its food and found that the dog still produced saliva. The dog therefore had been conditioned to associate the ringing of the bell with its food. Other animals can also be conditioned to respond to a variety of stimuli.

Sequence of events during reflex action is shown

- When the original stimulus (taste of food) caused salivation in the dog. This is simple reflex pathway.
- When the new stimulus (sound of a bell) caused the same response of salivation. This is the conditioned reflex pathway.

Activity 3.10: To demonstrate role of antagonistic muscles in movement

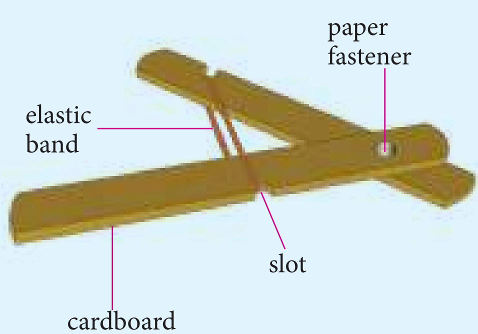
Work in groups

Materials

- Cardboards
- 50 metre rule
- 30 cm ruler
- Elastic bands
- Paper fastener

Procedure

1. Measure and cut (2) 40 cm by 10 cm cardboards.
2. Measure 15 cm from one end of the cardboard and cut a slot about 2 cm wide and in depth.
3. On the second cardboard, cut another slot with the same dimensions as in step (2); 5 cm from the edge.
4. Connect the cardboards using a paper fastener and place an elastic band through the two slots as indicated in figure below.



5. Stretch the elastic band by separating the cardboards. Draw an illustration to represent the position of the cardboards.
6. Release the tension on the elastic band by allowing it to shorten. Draw an illustration to represent the position of the two cardboards.

Study questions

1. Which position of the elastic band represents bicep muscles contraction and relaxation;
   i) Stretched elastic band?
   ii) Shortened elastic band?
2. Which bones are represented by the cardboards oriented;
   i) Horizontally?
   ii) Vertically?
3. How do the following affect the bones you have mentioned in 2 (i) above to do?
   i) Stretching of elastic band.
   ii) Shortening of elastic band.

Voluntary actions

These are actions done consciously by an animal i.e one is aware of them. They are initiated by the cerebral cortex of the brain. The actions include singing, writing, running and eating.

Table 3.3 Differences between voluntary actions and involuntary actions

Voluntary actions	Involuntary actions
They do not occur spontaneously.	Occurs spontaneously after receiving a stimulus.
They do not occur very rapidly.	Occur very rapidly.
Many neurons are involved.	Only three types of neurons are involved.
They are mediated by pathways in the cerebral cortex of the brain.	Are mediated by pathways either in the brain or spinal cord.
Responses to stimulus are always varying according to conditions.	Responses to stimulus are normally the same.

Table 3.3 continued

Autonomic nervous system

This is part of the nervous system that controls involuntary activities such as blinking. It is made up of two parts:

- Parasympathetic system
- Sympathetic system

The **sympathetic** system is important especially during emergency situations. It brings about responses associated with fight or flight. The parasympathetic nervous system controls internal responses associated with a relaxed state. These often cause antagonistic effects in the organs such as the heartbeat which may be accelerated by the sympathetic system while the parasympathetic system slows it down.

Check your progress 3.7

1. Which of these is an example of a conditioned reflex?
   A. Sneezing
   B. Yawning

C. Withdrawal of hand on touching a hot plate

D. Watering of mouth at the smell of food.

2. Reflex action is controlled by

A. Autonomic nervous system

B. Peripheral nervous system

C. Central nervous system

D. None of these

3. Which one illustrates a reflex arch?

A. Brain – spinal cord – muscles

B. Muscle – receptor – brain

C. Muscles – spinal cord – brain

D. Receptor – spinal cord – muscles

3.8 Chemical co-ordination in animals and the endocrine system

Activity 3.11: Research Activity

Work in groups

Your teacher will provide you with text books and computers with internet connection. Use the link below: http://ncerthelp.com/text.php?ques=Control+and+Coordination+Class+10+Notes+pdf+Science+Biology+CBSE

1. Research on the hormonal control in coordination in animals.

2. Relate the previous knowledge learnt on role of hormones in regulating plant growth and compare it to chemical coordination in animals and the endocrine system.

3. What are some similarities or differences observed? Explain.

The endocrine system produces hormones that work together with the nerve cells to bring about co-ordination during the process of irritability in animals. Hormones are chemical subs – tances produced in one part of the body and bring about responses in another part of the body. They are produced by endocrine glands also known as ductless glands. Fig 3.32 below shows various endocrine glands.

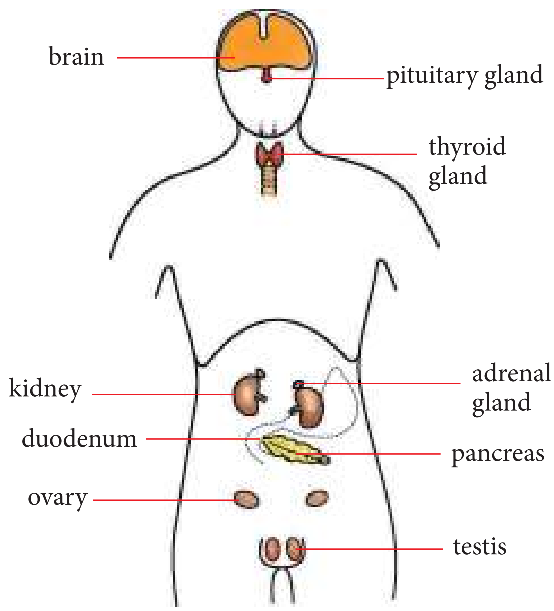


Fig 3.32: Position of endocrine glands in the human body

The endocrine glands produce hormones which are released into the blood circulatory system. As the blood circulates in the body, the hormones stimulate responses in specific organs. Such organs are called **target organs**.

Some endocrine glands are usually stimulated to release hormones by impulses that originate from the nervous system. Other endocrine glands release their hormones as a result of stimulation by hormones from other glands. Hormones are produced in very small quantities and stay for a while in the blood. As a result, their effects are felt for a longer time. In this section, we will discuss two hormones involved in coordination. These are **thyroxine** and **adrenaline**.

Thyroxine

Thyroxine hormone is produced by the thyroid glands found at the neck region. Thyroxine is a complex protein compound that contains iodine. It is released by the thyroid glands upon stimulation by another hormone known as the **thyroid-stimulating hormone** (TSH). The thyroid stimulating hormone is produced by the pituitary gland.

Role of thyroxine

Thyroxine controls the rate of chemical reactions in the body i.e. the metabolic rate. It does this because it is able to stimulate the formation of enzymes required for respiration. The energy released during respiration is required by the chemical reactions taking place in the body.

The chemical processes are important in growth and development. Thyroxine is therefore important in regulating rate of growth and development of the organism. In this way, thyroxine helps in coordinating the various processes that lead to normal growth and development. Thyroxine also controls the basal metabolic rate.

Effects of under-secretion of thyroxine (Hypothyroidism)

Under-secretion occur when thyroid gland produce less thyroxine than the amounts required for normal metabolism, growth and development. Under-secretion of thyroxine leads to the following conditions:

- If there is a deficiency of thyroxine at birth, this will lead to poor growth and mental retardation, a condition known as **cretinism.** If detected early, this condition can be rectified.
- If the deficiency occurs in an adult, it leads to a condition known as **myxoedema.** This condition is characterised by slow physical and mental activity in adults. The weight of the person increases due to the formation and storage of a semi-fluid material under the skin. The skin then becomes coarse and rough. Hair is also lost from the head. The thyroid gland swells to form the colloid goitre. This condition can be rectified by swallowing thyroxine tablets.

Effects of over-secretion of thyroxine (Hyperthyroidism)

Over-secretion of thyroxine occurs when the thyroid glands produce more thyroxine than required for the normal metabolism, growth and development. It is caused by swelling of the thyroid glands, a condition referred to as exophthalmic **goitre.** Over-secretion of thyroxine leads to increased metabolic rate in the body which results in the following:

- High body temperatures.
- Increased breathing rate and heart beat.
- Increased rate of breakdown of glucose, glycogen and fats leading to loss of body weight.
- Excess energy production that results to physical and mental restlessness. Such people become nervous and irritable and their hands shake when held out. The person has protruding eyes.

Health check!

A swelling of the thyroid gland (goitre) can be caused by both over-activity and under-activity of the thyroid glands. Over-activity may lead to over-secretion of thyroxine while under-activity leads to under-secretion of thyroxine. Goitre is also caused by lack of iodine in the diet.

Activity 3.12 Discussion Activity

Work in groups

1. Discuss an experience when you were chased by a dog. How did you react? What happened to your body?
2. Compare your encounter with those of other groups.
3. Which hormone do you think was responsible for such kind of a situation?

Adrenaline

The facts

During a stressful situation, your heart begins to race, your hands start to sweat and you start looking for an escape, a situation referred to as **fight** and **flight response**. The hormone produced in such a situation is known as **adrenaline** or **epinephrine hormone**.

Adrenaline is produced by glands known as **adrenal glands** found on the upper surface of the kidneys. The hormone is produced by the inner part of the adrenal glands known as the **adrenal medulla.** The production of adrenaline is stimulated by the nervous system. The hormone is involved in response to danger, anxiety, excitement and emergency. It is therefore sometimes referred to as the **flight hormone.**

Over production of adrenaline causes:

- Increased metabolism.
- Increased conversion of glycogen into glucose.
- Increased heart beat resulting in increased rate of circulation of blood and therefore the supply of glucose and oxygen to the muscles.
- Blood vessels serving non-vital organs such as the digestive system to constrict reducing blood supply to them.

- Blood vessels serving vital organs such as the lungs and the brain to dilate increasing blood supply to them.
- Increased rate of breathing to supply oxygen required for more energy production.
- Increased rate of muscle contraction enabling rapid movements.

These responses make the body ready to respond to emergency or threatening situations.

Underproduction of adrenaline causes:

- Reduced activity
- Fatigue
- Stress and slow response to danger

Table 3.4: Table showing the hormones produced by the endocrine system and their effects

Glands	Hormone produced	Effects or functions
Anterior pituitary gland	Thyroid stimulating hormone (TSH)	It stimulates the thyroid gland to produce the thyroxine hormones.
	Follicle stimulating hormone (FSH)	It stimulates egg development in the female and sperm development in the male. Stimulates the ovaries to produce oestrogen. Stimulates release of progesterone by the ovary. Stimulates testosterone secretion in testes.
	Luteinizing hormone (LH)	It causes ovulation in the females. It causes conversion of the grafian follicle into corpus luteum in ovaries. It stimulates testosterone secretion in the testes.
	Growth hormone (GH)	It stimulates growth especially bones. Excess in children results into gigantism and under secretion in children results into stunted growth (dwarfism).

Glands	Hormone produced	Effects or functions
Anterior pituitary gland	Adrenocorticotrophic hormone (ACTH)	It causes the adrenal cortex to secrete its hormones. Stimulates lipid breakdown to release of fatty acids from fat cells.
Posterior pituitary gland **Note:** Pituitary gland is the master gland	Anti-diuretic hormone(ADH) vasopressin	It causes reabsorption of water in the kidney nephrons i.e. Osmoregulation. Under secretion results in diabetes insipidus.
	Oxytocin	It brings about parturition (contraction of the uterus during birth). Stimulates milk flow from the mammary glands.
Thyroid gland (neck region)	Thyroid hormones: Triiodothyronine (T3) and Thyroxine (T4)	Controls metabolic activity, raises body metabolic rate (BMR). Excess results into an increased metabolic rate which leads to protrusion of eye balls. Under secretion leads to goitre.
Parathyroid glands	Parathyroid hormone	It increases iron calcium absorption.
Stomach	Gastrin	Stimulates secretion of gastric juice.
Duodenum	Secretin	Controls secretion of bile and pancreatic juices.
Pancreas (Islets of Langerhans)	Insulin	It controls the balance of sugar in blood by converting glucose to glycogen in case there is an excess. Under secretion results into diabetes mellitus.
	Glucagon	It converts glycogen into glucose.

Glands	Hormone produced	Effects or functions
Adrenal gland	Adrenaline	For flight and fight actions, by increasing heart rate and metabolic rate.
Ovary (lower abdomen)	Oestrogen hormone	It brings about healing and repair of the uterus wall after menstruation. It brings about development of female reproductive organs. It brings about development of secondary sexual characteristics. Deficiency causes delay in the development of secondary sexual characteristics.
	Progesterone	It promotes proliferation of the uterus wall. Controls the menstrual cycle. It maintains pregnancy.
Testis (produced in scrotum)	Testosterone (male sex hormone)	Development of male sexual characteristics. Deficiency causes delay in the development of secondary characters.

Functional differences and similarities between the endocrine and nervous systems

Activity 3.13: Discussion Activity

Work in groups

1. With your friends, discuss the differences and similarities between the endocrine and nervous systems.
2. Compare your findings with other groups.

As we had said earlier, both the nervous and the endocrine systems are involved in linking co-ordination. Since the two systems are involved in co-ordination, they therefore have some similarities and some differences.

The following are the functional similarities between the endocrine and the nervous system.

1. Both stimulate responses to specific stimuli. These responses are of survival value to the organisms.
2. Both are involved in co-ordination of body activities.

However, the two systems have several differences related to how they function. These differences are summarised in Table 3.5 below.

Table 3.5: Comparison of Hormonal and Nervous Control

	Nervous Control	Hormone Control
Communication	Impulses across synapses.	Hormones in the blood.
Speed	Very rapid (within a few milliseconds).	Relatively slow (over minutes, hours or longer).
Duration	Short term and reversible.	Longer lasting effects.
Target pathway	Specific (through nerves to specific cells).	Hormones broadcast to target cells everywhere.
Action	Causes glands to secrete or muscles to contract.	Causes changes in metabolic activity.

Table 3.6: Functional differences between the endocrine and the nervous systems

Glands (Endocrine system)	Nervous system
1. Uses chemical substances or hormones to relay impulses.	1. Uses electrical charges caused by concentration of chemical substances to relay impulse.
2. Hormones transmitted through the blood.	2. Impulses are transmitted through nerve cells.
3. Hormones reach all parts of the body.	3. Nerve impulses are transmitted through nerve cells connected to specific parts of the body.
4. Hormones stay longer in the blood and as a result, their effects last longer.	4. Impulses are short lived and as a result, their effects last for short periods of time.
5. Mostly involved in growth responses and some muscle activity.	5. Mostly involved in muscle contractions and stimulation of hormone secretion.
6. Responses are usually slow.	6. Responses are usually fast.

Application of hormones in food production

Activity 3.14: Research Activity

Work in groups

Your teacher will provide you with textbooks and journals.

1. Carry out a research on the use of hormones in food production.
2. Discuss the use of bovine somatotropin (BSTor bST) to increase milk production.
3. Present your findings in class.

The facts

Hormones are naturally present in human beings and animals for growth, development and reproduction. But many animals raised for meat and dairy production are being given additional hormones, natural and synthetic, to speed up the growth process and increase milk production.

A number of **steroid hormones** are used in beef cattle and sheep, including natural estrogen, progesterone, testosterone and their synthetic versions.

Drugs such as aspirin are used to prevent pain in an ailing person by decreasing the production of prostaglandins and thromboxane. Aspirin's ability to suppress the production of prostaglandins and thromboxanes is due to its irreversible inactivation of the cyclooxygenase enzyme. Other drugs such as tetracycline, streptomycin and penicillin have been used as common additives in feed for livestock and poultry. These drugs have been used in livestock and poultry feeds for improved performance in the animals such as efficient conversion of feed to animal products, an increased growth rate and a lower morbidity/mortality rate. The levels of antibiotics are often increased at different levels when specific diseases are being targeted as when the spread of a particular disease is rampant. The levels are also increased in times of stress. This increased amount is often decreased when the threat of a disease is gone.

These hormones are used based on studies that the food from the treated animals is safe for people to eat and that the drugs do not harm the treated animal or the environment. The drugs also have to be effective, meaning that they work as intended.

Some hormones are considered safe, such as recombinant bovine growth hormone (rBGH) which is used in meat and dairy production. However, there are significant concerns that residues of hormones found in meat and dairy products may interfere with human hormone balance and have a negative effect on human health, causing cancer, developmental and reproductive issues at the early onset of puberty in girls.

Oral contraceptives pills (birth-control pills) are used to prevent pregnancy. Estrogen and progestin are two female sex hormones. Combinations of both estrogen and progestin work by preventing ovulation i.e. (the release of eggs from the ovaries) from taking place and also changes the lining of the uterus (womb) so as to prevent pregnancy from taking place by thickening the mucus at the cervix (opening of the uterus) to prevent sperm from entering. Oral contraceptives are a very effective method of birth control, but they do not prevent the spread of Human Immunodeficiency Virus (HIV) and AIDS and other sexually transmitted diseases.

Dairy cows are often injected with recombinant bovine growth hormone (rBGH), also known as recombinant bovine somatotropin (rBST) to increase milk production. The hormone is believed to be present in milk in small quantities and it is broken down by the digestive tract. However, this hormone also raises levels of Insulin Growth Factor-1 in cows, which is linked to tumour growth in human beings. Cows that have been treated with rBGH are more susceptible to mastitis, an udder infection, due to increased milk production. The infection must be treated with antibiotics, contributing to the real and growing problem of antibiotic resistance.

Hormones present in cow manure also lead to environmental issues as they easily enter water sources, negatively affecting aquatic ecosystems.

Check your progress 3.8

1. How is the circulatory system involved in the functions of the endocrine system?
2. Why is the ingestion of dietary iodine so important for thyroid function?
3. What is the importance of blood glucose levels for human health?

Unit 4

Homeostasis in plants and animals

Learning outcomes

Knowledge and understanding	Skills	Attitude
• Describe the role and operation of homeostasis in animals and plants	• Design and carry out investigations on the movement of water across plant and animal cell membranes, make observations and apply this to organ systems • Closely observe mammalian organ structure and relate this to function and record observations	• Evaluate and appraise the complexity of homeostatic processes • Appreciate the role of water, salt, etc in supporting life.

Introduction to homeostasis

In Secondary 2, you learnt about homeostasis. Can you remember what homeostasis is? What is the role of homeostasis in plants and animals based on what you learnt in Secondary 2? Now look at these pictures. What do you think the animals are doing? Why are they doing so? Explain your answer based on the knowledge you acquired in Secondary 2.

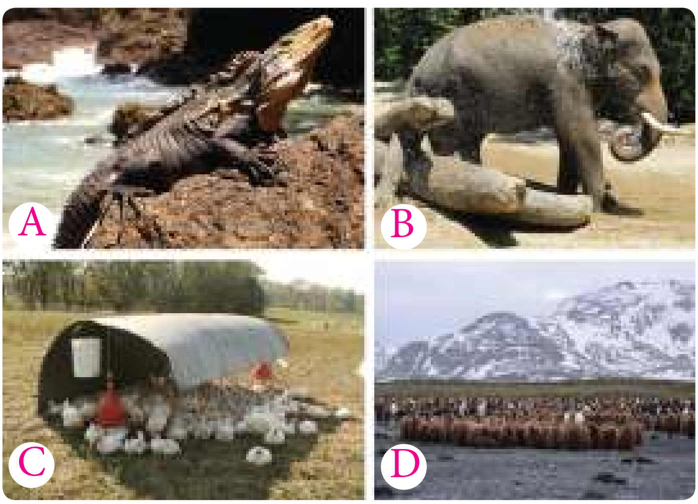


Fig 4.1: Homeostasis in animals

Activity 4.1

Work as a group.

1. Share with your friend what you do when its very cold.
2. Why do you do so?
3. Discuss two examples of plants and animals in relation to how they regulate their body temperature in their environments.

4.1 Definition of homeostasis

Homeostasis is the term used for the body's ability to maintain a constant internal environment. This condition is important for the proper functioning of the body because the enzymes that control all metabolic activity essential for life are very sensitive to changes in their environment. This constant state must be maintained in spite of changing the external environment.

Species that have efficient homeostasis systems are able to tolerate a wide range of external factors. Apart from water, which is regulated by the kidneys (the kidneys are responsible for maintaining the levels of mineral salts as well), other substances and conditions must be kept relatively constant such as carbon dioxide concentration, blood glucose levels and body temperature.

An example of homeostasis is the control of blood sugar levels in the human body. If carbohydrates are ingested in excess, they will be digested and the excess converted to animal starch (also known as glycogen) by the linking of glucose molecules. This is accomplished by the hormone insulin which is secreted from the pancreas.

- What happens when you consume large quantities of bread? And what happens when you skip lunch or dinner? The first thing is we often feel a bit weak, as there is a lack of sugar in the body. As a result, the body begins to actively convert glycogen back to glucose, in order to increase the blood glucose level.

Animal organs and organ systems constantly adjust to internal and external changes in order to maintain this steady state. There are three important aspects of homeostasis.

a) Osmoregulation
b) Thermoregulation
c) Excretion

Activity 4.2

Work as a group.

1. a) What do people do when the weather is hot? What about if the weather is cold?
   b) Why do they do the things in (a) about?
2. a) Observe also how animals behave during a hot and cold season.
   b) Why is this so? Explain.

To maintain cells, tissues and the organism within their biological tolerance limits, various mechanisms have evolved:

a) **Structural:** the organism has particular physical features, which help its survival in an otherwise hostile environment.
b) **Functional:** the metabolism of the organism is able to adjust to changes in conditions as they are detected.
c) **Behavioural:** the actions and interactions of the individual, either alone or with others, which help it to survive in its particular environment.

Homeostasis therefore is the combined result of all of these; a failure of any one of them can result in the death of an individual. The two systems of the body which are directly involved in maintaining homeostasis are the **nervous** system and the **endocrine** (hormone) system.

Factors that must be kept constant

Activity 4.3

Work as a group.

Requirements

- A freshly excised heart of either a frog or a small mammal (rabbit or guinea pig). Make sure that the heart is still adequately oxygenated.
- Made solutions of sodium, potassium and calcium ions.
- Container, trough or basin
- Gloves

Procedure

1. Your teacher will demonstrate or play a video clip of this activity by exposing the heart into a mixture of sodium, potassium and calcium solution in a basin. Observe carefully.
   - What happens when the frog's heart is exposed to a mixture of sodium, potassium and calcium ions?
2. Compare such solutions to the ones found inside the human body.

The facts

All tissues can be kept alive in a suitable mixture of ions similar to the tissue fluids. Such solutions, which vary according to the species, are known as **physiological saline**.

The most important features of the internal environment that must be kept constant include:

a) Chemical constituents such as glucose, ions and others.
b) Osmotic pressure, determined by the relative amounts of water and solutes.
c) The level of carbon dioxide.
d) Temperature

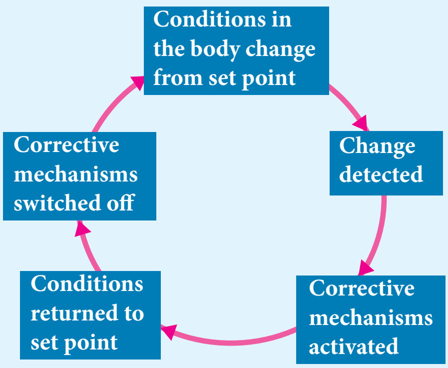
In addition, certain chemical materials must be eliminated completely from the body. The most important of these are nitrogenous waste products arising from protein metabolism and toxic substances released by pathogenic microorganisms.

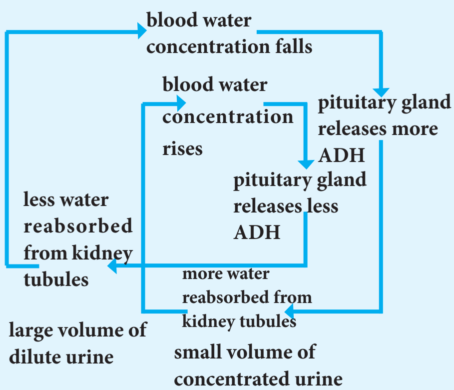
Feedback mechanisms

Activity 4.4

Work in pairs.

1. Discuss the meanings of the terms:
   - Stimulus
   - Receptor
   - Relay
   - Effector
   - Response
   - Feedback
2. Study the flow diagrams below.





(a) What kind of mechanism is illustrated above?

(b) Compare your findings with the rest of the class.

The facts

A **feedback loop** is a biological occurrence where the output of a system amplifies the system (**positive feedback**) or inhibits the system (**negative feedback**).

Feedback loops have certain essential components, whether they are positive or negative:

- **Stimulus:** the change from ideal or resting conditions.
- **Receptor:** the cells or tissue which detect the change due to the stimulus.
- **Relay:** transmission of the message, via nerves or hormones or both, to the effector.
- **Effector:** the cells or tissue (gland or muscle), which cause the response to occur.
- **Response:** an action, at cell, tissue, or whole organism level, which would not have occurred in the absence of the stimulus.
- **Feedback:** the consequence of the response on the stimulus, either positive or negative.

Feedback mechanisms are the general mechanism of either nervous or hormonal regulation in animals. Feedback occurs when the response to a stimulus has an effect of some sort on the original stimulus. They can either be positive or negative.

a) Negative feedback

Occurs when the response to a stimulus diminishes the original stimulus. Negative feedback is most common in biological systems.

- Blood glucose concentrations rise after a meal (the stimulus) and insulin causes glucose to be removed from the bloodstream (the response), which decreases blood glucose.
- Physical exercise creates metabolic heat that raises body temperature (the stimulus) and vasodilation and sweating (the response) cools the body.

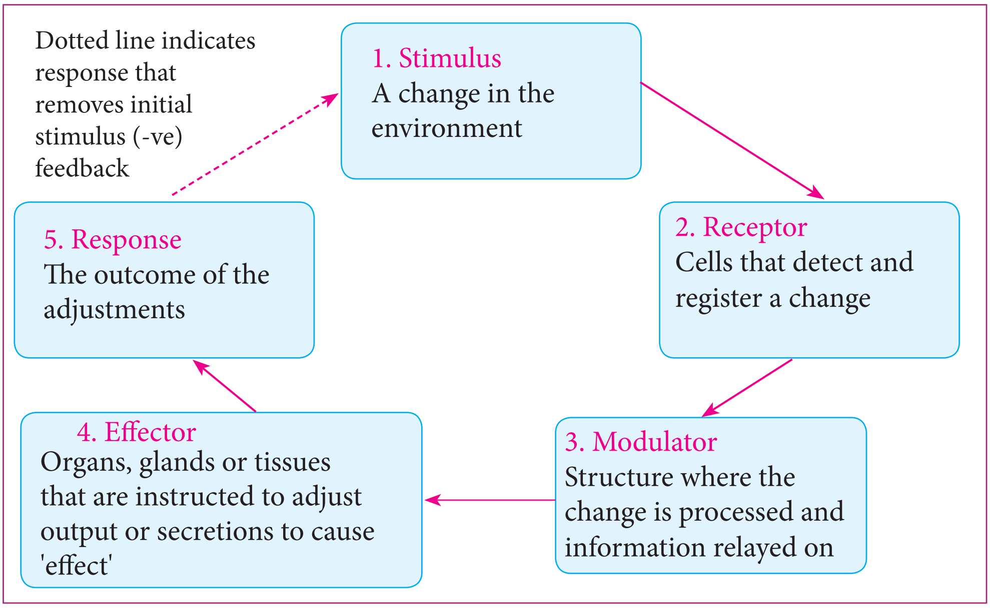


Fig 4.2: Negative feedback mechanism

Activity 4.5

Work in pairs

1. - Observe a fruiting tomato field, a mature green banana or even a mango tree that is fruiting.
   - What do you notice after a few days or weeks?
   - What contributes to the effect you have observed?
2. What happens when you cut yourself? How long does it take the blood to clot?
2. Prepare a report of your findings and present it in class.

b) Positive feedback

Occurs when the response to a stimulus increases the original stimulus. It is rare in biological systems.

- When a baby first suckles its mother's nipple, a small amount of breast milk is released (the stimulus) and a hormone is released which increases milk production (the response).
- A ripening banana releases ethylene (the stimulus), which accelerates the ripening of unripe bananas near it, releasing more ethylene (the response).

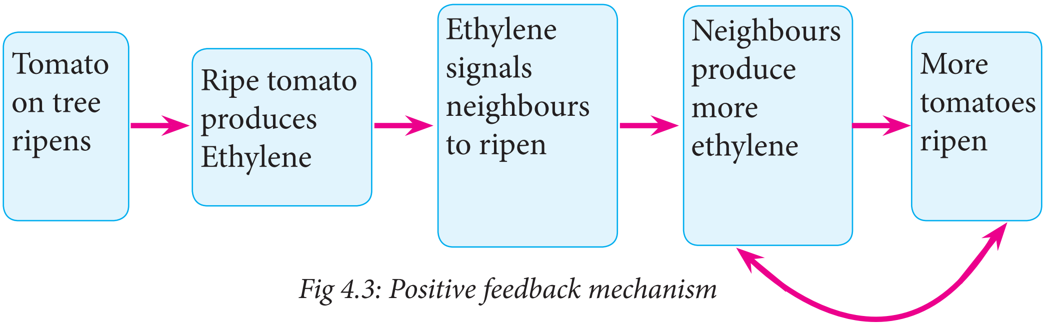


Fig 4.3: Positive feedback mechanism

Blood clotting

Activity 4.6: Determining the process of blood clotting

Work in pairs

You will be provided with simulations and visual materials.

1. Use the materials to come up with a mechanism involved in the blood clotting process.
2. Compare your finding with the rest of the class.

Study questions

(a) Have you recently suffered a cut or bruise on any part of your body?

(b) Do you know somebody who has?

(c) How long did the injured part bleed?

(d) What did you see at the injury site after the bleeding stopped?

The facts

A **blood clot** is a seal that forms to close blood vessels that are cut or damaged. This stops further bleeding at the wound and therefore prevents excessive blood loss. It also prevents entry of harmful bacteria into the body through the damaged tissue.

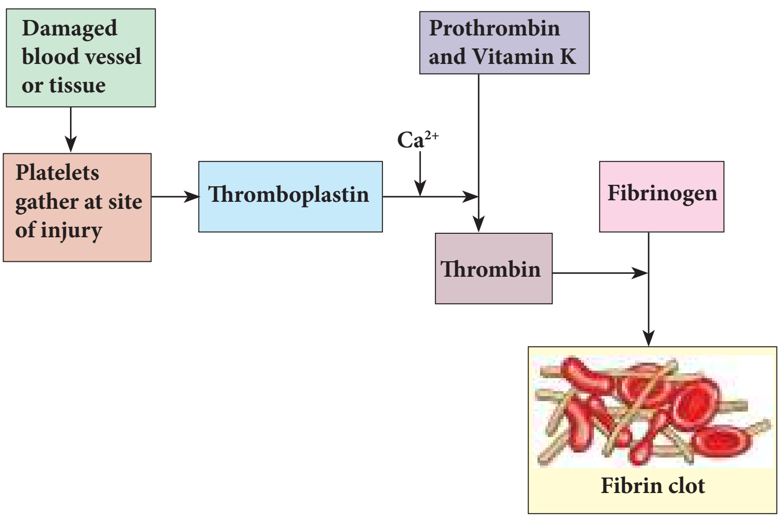


Fig 4.4 The process of blood clotting

When blood vessels are damaged, for example a cut on the skin, the damaged tissue and **platelets** (**thrombocytes**) release a chemical called **thromboplastin** (thrombokinase). This substance converts a blood protein called **prothrombin** to enzyme thrombin. Thrombin in turn changes soluble blood protein **fibrinogen** into insoluble **fibrin**, a mesh of fibres which traps red blood cells. This generates a clot which shrinks as it forms hence pulling the edges of the wound together and assists in its sealing. It dries up to form a scab which protects the wound, giving the tissue beneath time to heal. **Vitamin K** is needed for prothrombin to be formed in the liver.

If a clot forms internally, a condition known as thrombosis occurs. We have seen that thrombosis can be fatal if the clot formed enters and blocks fine capillaries that provide oxygen and nutrients to vital organs like the brain or heart.

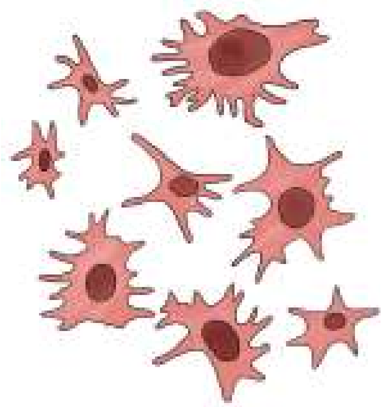


Fig 4.5: Platelets

Activity 4.7

Work in groups

1. Using the Internet and available library resources, carry out a research on the following feedback loops:
   a) Blood clotting
   b) Blood oxygen levels
   c) Temperature regulation
   d) Body pH levels
   e) Osmoregulation (water and salt concentrations)
   f) Blood calcium levels
   g) Blood pressure
   h) Fever (different from normal temperature regulation)
2. Use the following guidelines to write your report.
   - Identify if it is an example of negative or positive feedback.
   - Identify the stimulus, receptor, effector and response of this feedback loop.
   - Identify what body systems are involved and how they work.
   - What are the consequences if this feedback loop does not end?

Importance of feedback mechanisms

Activity 4.8

Work in groups.

1. Discuss the importance of feedback mechanisms in the body.
2. Present your findings to the class.

The facts

Without feedback, homeostasis cannot occur.

i) This means that organisms lose the ability to self-regulate their bodies.

ii) Negative feedback mechanisms are more common in homeostasis, but positive feedback loops are also important.

iii) Changes in feedback loops can lead to various issues, including diabetes mellitus.

Check your progress 4.1

1. a) Differentiate between negative and positive feedback mechanisms

   b) Fill the following table with examples of negative and positive feedback mechanisms in the human body.

Negative	Positive

2. What is the importance of regulating the internal environment in organisms?

Homeostasis in plants

Activity 4.9

Work in groups

Requirements

- Different type of plant leaves
- Compound microscope
- Clear nail polish
- Razor blade or scissors
- Microscope slides and cover slips
- Clear tape

Procedure

a) Bring different type of leaves and paint a thick layer of clear nail polish on one surface.

b) Allow the polish to dry completely.

c) Place a piece of clear tape over the nail polish patch.

d) Peel off the tape of the leaf and remove the nail polish.

e) Tape the nail polish to a slide and trim off any excess tape with a razor blade.

f) View the leaf on a microscope under high power magnification.

g) Are the stomata open or closed? What can this tell you about the plant?

h) Focus on one stoma and observe how the guard cell look like.

i) Repeat this procedure with other type of leaves. Are the number of stomata the same? Explain?

The facts

Plants do not have an elaborate homeostasis mechanism because waste products from one process may be used in another process. Other waste products may be stored in harmless forms. Therefore in plants, **stomata** are a key component to maintaining internal plant environment as it continuously exchanges oxygen and carbon dioxide with the atmosphere.

Opening and closing of the stomata helps in:

- Transpiration
- Transport of water and mineral salts from root to shoot in the transpiration pull. This maintains internal body temperature.
- It also maintains the concentration of potassium and sodium ions. Water follows these ions and as a result, the turgidity of the guard cells increases and the stomata opens.

Stomata have daily rhythms of opening and closing and also respond to changes in environmental conditions.

The opening and closing of the stomata is controlled by the guard cells. In light, guard cells take up water by osmosis and become turgid. Because their inner walls are rigid, they are pulled apart, opening the pore. In darkness, water is lost and the inner walls move together, closing the pore.

Opening and closing of stomata

Table 4.1: Factors affecting opening and closing of stomata

Stomata open due to	Stomata close due to
• High light intensity • Low concentration of carbon dioxide	• Darkness • High concentration of carbon dioxide • Low humidity • High temperature • Water stress

Note: Abscisic acid (ABA) is a **stress hormone** that is secreted in response to difficult environmental conditions such as very high temperatures or much reduced water supplies. It triggers the closure of stomata to reduce transpiration and prevent water loss.

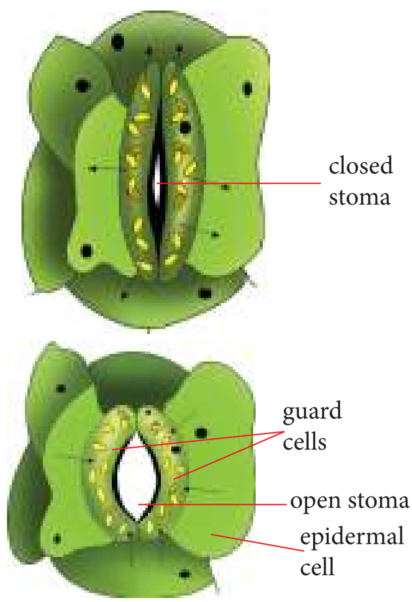


Fig. 4.6: Structure of the stoma when open

and closed

Check your progress 4.2

1. Give the reason why plants do not have an elaborate homeostatic process.
2. Which wastes are produced by plants and reused?
3. Explain why the desert rat and other desert animals do not have to drink much water. Where does it gain most of its water from?

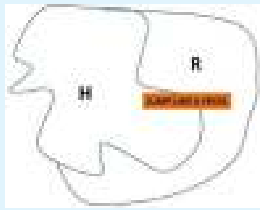
4.2 The role of endocrine system in homeostasis

In the previous sub-unit, we learnt about chemical coordination in animals and the endocrine system. In this sub-unit, we will focus on the role of hormones in homeostasis.

Activity 4.10:

Work as a class

1. This is a class activity; divide into a group of hormones (H) and a group of receptors(R). The hormones have to find their matching receptors, and the pair, once matched, performs a given action.
2. Create puzzle pieces by cutting shapes out of cardboard and cut them in half, or use pieces from a jigsaw puzzle and label the back (plain) side of them.
3. Each pair of puzzle pieces should be labelled: with an H on one half for hormone, and with an R for receptor on the other half.
4. Write an action across both pieces, so that it can only be fully read when they are joined together. Possible actions include: jump like a frog, crow like a cock, mew like a cat, nod like a gecko as shown below.



5. Pass out the puzzle pieces, but do not to look at the label on your piece.
6. Scatter throughout the entire classroom and then freeze.
7. Now look at your pieces:
   - If you are a "receptor" remain frozen in place.
   - If you are a "hormone", you may now move throughout the classroom.
   - Each "hormone" student must try to match his or her piece with each receptor piece until they successfully find a match.
8. Once you have all matched your pieces (i.e. found your match), act out together the action written on your puzzle pieces.
9. What have you learned from this exercise?

The facts

The endocrine system is a chemical control system in plants and animals whose function is to control the internal environment (homeostasis). This chemical control system acts together with the nervous system.

The endocrine system maintains homeostasis and long-term control using chemical signals. It works in parallel to the nervous system to control growth and maturation along with homeostasis. It is a collection of glands that secrete chemical messengers called hormones.

Hormones travel through the bloodstream to arrive at a target organ.

- Cells of the target organ possess the appropriate receptor proteins.
- Cells without these receptors are not affected by the hormone.

Note: Not all glands are part of the endocrine system. Exocrine glands secrete products out of the body, for example sweat glands, salivary glands and digestive glands.

Hormones can be steroids (e.g. testosterone), peptides (e.g. insulin) or amines (e.g. thyroid hormone).

Human endocrine system

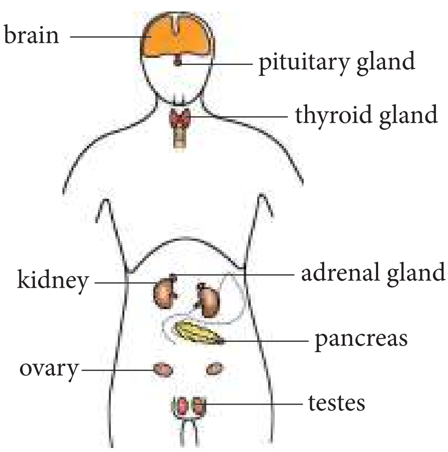


Fig 4.7: Position of the endocrine glands in the human body

Regulation of hormones

Levels of hormones in the blood are controlled by the following mechanisms:

- When one hormone stimulates production of a second, the second suppresses the production of the first.
- Follicle stimulating hormone (FSH) stimulates release of estrogen, and high levels of estrogen suppress production of FSH.
- Antagonistic pairs of hormones.
- Insulin causes the level of blood glucose to drop when it is too high, and glucagon causes it to rise when it has dropped too low.
- Hormone secretion is increased (or decreased) by the same substance whose level is decreased (or increased) by the hormone.
- An increase in Ca^{2+} in the blood suppresses the production of parathyroid hormone. A low level of Ca^{2+} stimulates it.

Nervous regulation of homeostasis

- Sensory receptors are constantly monitoring both the external and internal environments.
- These receptors pass impulses along sensory neurons to the CNS in response to stimuli (e.g. change in body temperature or a visual stimulus).
- The brain processes sensory input and coordinates a response.
- Motor neurons carry impulses to the effectors, the muscles and glands.

Control of blood glucose

Blood glucose is maintained within a very narrow range. Insulin and glucagon, produced by the pancreas, are responsible for control of blood glucose levels, which is actually monitored by the pancreas.

Insulin:

- is secreted by β-cells in the Islets of Langerhans (in the pancreas).
- is stimulated by high blood glucose (but always produced).
- causes skeletal muscles, liver and fat cells to absorb glucose from the bloodstream and convert it to glycogen or fat (for storage).

Glucagon:

- is secreted by α-cells in the Islets of Langerhans.
- is stimulated by low blood glucose.
- causes skeletal muscles and liver to convert glycogen to glucose, which is released into the blood. The normal range for blood glucose is between 70 mg/dl and 110 mg/dl.
- 110 mg/dl may occur 2-3 h after a meal
- >180 mg/dl indicates hyperglycemia, and may indicate diabetes.

Type 1 Diabetes is a condition where the pancreas produces insufficient amounts of insulin. Glucose builds up in the body instead of being used for energy. It is often called juvenile diabetes because it is diagnosed in childhood/early teens. People with type 1 diabetes need to monitor their blood sugar levels, and keep it within narrow limits by:

- taking insulin as required (other medications may also be prescribed).
- eating healthy meals and snacks.
- enjoying regular physical activity.

Table 4.2: Symptoms and treatment of Type 1 diabetes

Symptoms	Treatment
• Constant thirst	• Injection of insulin into the bloodstream daily.
• Undiminished hunger	• Regular measurement of blood glucose level.
• Excessive urination	

Type 2 Diabetes is a progressive, life-long condition in which the pancreas either does not produce enough insulin, or the body does not properly use the insulin it makes. Over time it may be more difficult to manage symptoms and keep blood sugar within the prescribed range.

Table 4.3: Symptoms and treatment of Type 2 diabetes

Symptoms	Treatment
• Mild – sufferers usually have sufficient blood insulin, but insulin receptors on cells have become defective.	• Largely by diet/exercise alone-may require insulin therapy and other medications later in life.

Check your progress Test 4.3

1. What role do sweat glands play in the regulation of temperature in a mammal?
2. Why does an athlete pant after running a race?
3. Why is it important that the glucose is reabsorbed back into the bloodstream?
4. The kidney is an organ that carries out excretion and osmoregulation. Explain what is meant by these two terms.

Thermoregulation

Activity 4.11:

Work in pairs

Watch a video from this URL: http://openstaxcollege.org/l/thermoregulate2

1. How do elephants regulate their body temperature?
2. How are polar bears able to live in extremely cold temperatures?

The facts

Thermoregulation is a process of regulation of the body temperature to ensure the body's physiological state is at a normal constant level.

Animals can be divided into two groups:

- Homeotherms, i.e. those that maintain a constant body temperature in the face of differing environmental temperatures, and
- Poilkilotherms, i.e. those that have a body temperature that is the same as their environment and thus varies with the environmental temperature.

Animals that do not have internal control of their body temperature are called ectotherms.

- The body temperature of these organisms is generally similar to the temperature of the environment, although the individual organisms may do things that keep their bodies slightly below or above the environmental temperature. This can include burrowing underground on a hot day or resting in the sunlight on a cold day. Ectotherms are also known as cold-blooded animals, a term that may not apply to an animal in the desert with a very warm body temperature.

An animal that maintains a constant body temperature in the face of environmental changes is called an endotherm.

- These animals are able to maintain a level of activity that an ectothermic animal cannot because they generate internal heat that keeps their cellular processes operating optimally even when the environment is cold.

Skin and its role in temperature regulation

Activity 4.12: To observe prepared slides, diagrams and models of a mammalian skin

Work in groups

Requirements

- Prepared slide of a vertical section of a mammalian skin
- Microscope
- Charts and diagrams
- Model of the skin

Procedure

1. Place the prepared slide under the microscope.
2. Examine the slide first under low power and then under high power.
3. Compare your observations with diagrams and the skin model provided.
4. Identify the two main parts of the skin: the epidermis and the dermis.

Note: The malpighian layer with its clear nuclei appears granular. The cells of the malpighian layer are pigmented towards the outer surface.

5. Locate other parts of the skin such as hair follicle, sebaceous glands, sweat gland and hair.
6. Draw and label what you observe.

The facts

The skin consists of two main layers, that is an outer **epidermis** and an inner **dermis.**

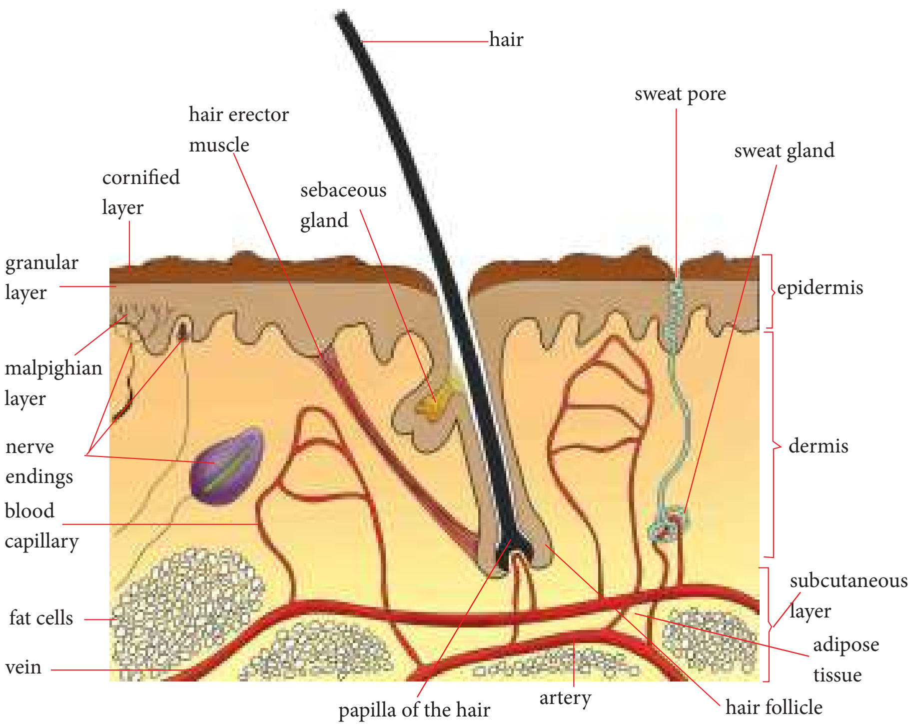


Fig 4.8: A section through the mammalian skin

The epidermis

It is the upper layer of the skin. The epidermis is made up of three layers of cells. The three layers are **cornified** layer, **granular** layer and **malpighian** layer.

(i) The cornified layer

The cornified layer is the outermost layer in the epidermis. It is made of dead cells which form a tough protective outer layer that acts as a barrier against entry of micro-organisms. It reduces loss of water and protects the inner cells from mechanical damage.

The cells in this layer produce large amounts of tough waterproof protein called **keratin** which strengthens them. The thickness of this layer varies from one part of the body to another. For instance, it is thicker in the soles of the feet because of the high level of friction between the feet and the ground. As the layer wears away, it is replaced by new cells formed in the Malpighian layer.

(ii) The granular layer

The granular layer is made of living cells which eventually form the cornified layer. It is the middle layer of cells in the epidermis.

(iii) The Malpighian layer

The Malpighian layer is the innermost layer of cells of the epidermis. It is made up of actively dividing cells which are responsible for the renewal of the epidermis. The cells in this layer contain **melanin** pigment which contributes to the colour of the skin. The more it is, the darker the skin colour. Melanin protects against ultra violet light from the sun which can damage the skin cells beneath it.

Caution: Certain substances in skin creams destroy melanin and cause damage to the skin. Such creams should not be applied on the skin.

The dermis

This is thicker than the epidermis and is located below it. It contains hair follicles, sweat glands, blood capillaries, nerve endings, lymph vessels, sensory organs and sebaceous glands.

(i) Sweat glands

These are tiny coiled tubes which secrete and release sweat through pores on the surface of the skin. Sweat consists of water and mineral salts such as sodium chloride and traces of urea and lactic acid. The liquid that forms sweat is absorbed by the sweat glands from the blood capillaries supplied to each gland. It reaches the surface of the skin through the pore and the water in it evaporates into the air.

(ii) Blood capillaries

There are many blood capillaries in the skin. They supply the cells in the skin with oxygen and nutrients and take away carbon dioxide and waste substances.

(iii) Hair follicles

These are tiny pits in the dermis. Hair grows inside the follicle due to addition of cells to it at the bottom of the pit. Hair is made up of dead cells and protein called **keratin**.

(iv) Sebaceous glands

Sebaceous glands are small glands which open into the hair follicle. They produce an oily secretion called **sebum** which keeps the skin soft and has antiseptic properties to kill bacteria on the skin.

(v) Hair erector muscle

The erector muscle is attached between the bottom part of the hair follicle and the epidermis. When it contracts the hair fibres stand upright and very small pimples or swellings appear on the skin. When it relaxes the hair lies flat on the skin.

Beneath the dermis is a layer of cells in which fat is stored. This layer is called the **subcutaneous fat layer.** It acts as a heat insulator.

Functions of the skin

a) Excretion

The skin eliminates waste substances like traces of urea, excess salts and water through sweat.

These substances are transported to the sweat gland through the blood capillaries. They diffuse out of the blood into the sweat gland to form sweat, which moves to the skin pore on the surface through a sweat duct. Sweat evaporates from the sweat pore into the environment, eliminating the waste products in the process.

b) It acts as a sensory organ

Due to the presence of the nerve endings and the sensory organs, the skin makes the body aware of the changes in the external environment through the senses of touch, heat, pressure and pain. This causes the body to respond appropriately to the changes.

c) Protection

- The skin prevents micro-organisms and other foreign materials from entering the body. It acts as a barrier between the external and internal environments in the defense of the body against pathogens and mechanical injury.
- Since the outermost layer is waterproof, the skin also prevents the body from drying out.
- It produces melanin which protects the body from ultra-violet radiation. This kind of radiation can cause skin cancer.
- The skin also manufactures Vitamin D through the action of sunlight on it. This vitamin is necessary for the formation and maintenance of bones. The skin acts as a receptor site for stimuli i.e. touch and pain.

d) Temperature regulation (Thermoregulation)

The skin plays an important role in the regulation of temperature in organisms whose body temperature is kept constant.

Activity 4.13: Discussion Activity

Work in groups

a) Go outside the class and bask in the sun for about 10 minutes. How does your skin respond?

b) Move away from the sun and now rest under a shade. How do you feel?

c) How does your skin respond?

d) Let your friend pour cold water on your arm. How does your skin respond?

e) Record your observations in your notebook and share with the rest of the class.

Thermoregulation in plants

Activity 4.14

Work as a class

Watch a video clip from the following link: https://www.youtube.com/watch?v=iKIRYkTrhR8

Study questions

1. How do plants regulate temperatures in their surroundings?
2. Why is this important for plants? Explain.

The normal range of temperature in plants is 10°C to 35°C. The adaption of plants to low and high temperature are as follows.

Low temperature

At low temperatures the nature of plasma membrane is changed and it produces a crystalline structure because the transport of solute is slow.

- At freezing point, ice crystals are formed in the cell. But the plant in cold regions change the composition of solute of the cell so ice crystal are not formed in the cytoplasm but form in cell the wall. This condition is known as freezing tolerance.

High temperature

High temperature is more harmful than low temperature for plant.

- Due to high temperatures, all enzyme are denatured and the metabolic process stops. Plants therefore increase the rate of transpiration and cool the body.
- At above 40°C, plants produce heat shock proteins. These proteins protect the enzymes from destruction.
- In some plants, a shiny cuticle is present which protects them from high temperatures.
- In some plants, leaves are reduced in size.

4.3 Osmoregulation

Activity 4.15

Group work

How are penguins able to live in extremely cold temperatures?

The facts

Osmoregulation is the process of maintaining salt and water balance (osmotic balance) across membranes within the body. It is part of homeostasis.

The fluids inside and surrounding cells are composed of water, electrolytes and nonelectrolytes. An electrolyte is a compound that dissociates into ions when dissolved in water.

- A nonelectrolyte, in contrast, does not dissociate into ions in water. The body's fluids include blood plasma, fluid that exists within cells, and the interstitial fluid that exists in the spaces between cells and tissues of the body.
- The membranes of the body (both the membranes around cells and the "membranes" made of cells lining body cavities) are semipermeable membranes.

Semipermeable membranes are permeable to certain types of solutes and to water, but typically cell membranes are impermeable to solutes.

The body does not exist in isolation.

- There is a constant input of water and electrolytes into the system. Excess water, electrolytes and wastes are transported to the kidneys and excreted, helping to maintain osmotic balance.
- Insufficient fluid intake results in fluid conservation by the kidneys. Biological systems constantly interact and exchange water and nutrients with the environment by way of consumption of food and water and through excretion in the form of sweat, urine and faeces. Without a mechanism to regulate osmotic pressure, or when a disease damages this mechanism, there is a tendency to accumulate toxic waste and water, which can have dire consequences.

Mammalian systems have evolved to regulate not only the overall osmotic pressure across membranes, but also specific concentrations of important electrolytes in the three major fluid compartments: blood plasma, interstitial fluid and intracellular fluid. Since osmotic pressure is regulated by the movement of water across membranes, the volume of the fluid compartments can also change temporarily. Since blood plasma is one of the fluid components, osmotic pressures have a direct bearing on blood pressure.

Osmoregulation in animals

Osmoregulation in terrestrial animals

In land animals, excretion of water takes place through the body surface so they have developed a number of strategies to maintain osmoregulation.

a) Water proof external covering. Epidermis present in reptile and mammals, cuticle present in insects prevent water loss from their body.

b) Storage and excretion of solid wastes in birds, reptiles and insects stored as nitrogenous waste (uric acid). Uric acid is insoluble in water and help to reabsorption of water in cloaca. Uric acid excreted the body in the form of paste and crystal.

c) Use of metabolic water: Some mammal fat is converted into simple compound and during this process water is produce which is reused in the body. Camel, kangroo used metabolic water.

d) Storage of harmful waste in mammal urea in kidney which is helps in reabsorption of water.

Osmoregulation in aquatic animals

Osmoregulation in fresh water animal is maintained by two methods.

a) By contractile vacuole

b) By producing dilute urine

1. By contractile vacuole

Fresh water unicellular organisms have contractile vacuoles. Water with dissolved CO_2 and uric acid is collected from the endoplasm into the contractile vacuoles, which increase in size up to a maximum and burst open, releasing the extra to the substance in environment.

In amoeba and paramicium, the amount of water and other substances remains balanced by contractile vacuole.

2. By producing dilute urine

Fresh water fishes have hypertonic body fluid as compare to the surrounding water. Fish release the extra amount of water in the form of dilute urine and absorb some essential ion from outside to maintain the salt and water content in the body.

Osmoregulation in marine animals

Marine water fishes have hypotonic body fluid than surrounding water because sea water is a high concentration of salt. These fishes drink water continuously and the salt is excreted out along with concentrated urine. They also excrete salt through the gills.

Excretion in animals

In animals, removal of nitrogenous waste from the body is very essential. Animals have particular organs to excrete nitrogenous waste.

Waste substance of animal

Animals produce different types of waste substances such as:

i. Ammonia
ii. Urea
iii. Uric acid
iv. Creatinine
v. Hypozenthine

Excretion in cockroaches

Cockroaches have a special tube - like excretory structure called "malphighian tubules". It is present between the mid gut and hind gut. It is embedded in the blood.

Malphighian tubules absorb all nitrogenous waste from the blood and pour them into illium. The latter part of the tubules reabsorbs important substances. The uric acid, when it gets to the rectum, has the water and salt reabsorbed, so uric became almost dry. It is then excreted from the body.

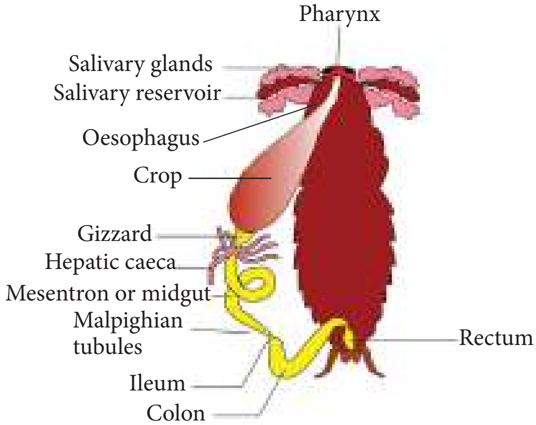


Fig 4.9: Alimentary canal of a cockroach

Osmoregulation in single-celled animals

Class discussion

Osmoregulation in paramecium and amoeba

Paramecium and amoeba live in fresh water. Their cytoplasm contains a greater concentration of solutes than their surroundings and so they absorb water by osmosis. The excess water is collected into a contractile vacuole which swells and finally expels water through an opening in the cell membrane.

In amoeba, the vacuole forms near the posterior end but is not associated with a particular structure. Although it empties its contents through an opening in the cell membrane, this also does not appear to be a permanent pore.

Paramecium has two contractile vacuoles, one at each end, which fill and contract alternately. They are permanent structures and the surplus water is conducted to the vacuoles by a series of radiating channels.

That the mechanism by which contractile vacuoles collect water involves expenditure of energy is evidenced by numerous mitochondria that lie close to the vacuole membrane.

Activity 4.16:

- What will happen when amoeba is treated with metabolic poison?
- Metabolic poison puts contractile vacuole out of action, with the result that the organism takes up water, swells and dies.

Watch a video provided on the following link:

www.youtube.com/watch?v=gHmUhYZ8_Q4

Did you know?

Marine species of amoeba, whose internal fluids are isotonic with the surrounding environment (in this case sea water) have no contractile vacuoles?

The kidney and homeostasis

While we think of the kidney as an organ of excretion, it is more than that. It does remove wastes, but it also removes normal components of the blood that are present in greater-than-normal concentrations.

i. When excess water, sodium ions, calcium ions and so on are present, the excess quickly passes out in the urine.

   On the other hand, the kidneys step up their reclamation of these same substances when they are present in the blood in less-than-normal amounts.

ii. Thus the kidney continuously regulates the chemical composition of the blood within narrow limits.

iii. The kidney is one of the major homeostatic devices of the body.

Mammalian excretory system

The facts

Mammals have a pair of bean-shaped kidneys.

- Each kidney is supplied with blood by a renal artery and drained by a renal vein.
  - In humans, the kidneys account for less than 1% of body weight, but they receive about 25% of the blood exiting the heart.
- Urine exits each kidney through a duct called the ureter, and both ureters drain into a common urinary bladder.

- During urination, urine is expelled from the urinary bladder through a tube called the urethra, which empties to the outside near the vagina in females or through the penis in males.
  - Sphincter muscles near the junction of the urethra and the bladder control urination.
- The mammalian kidney has two distinct regions: an outer renal cortex and an inner renal medulla.
- Both regions are packed with microscopic excretory tubules, nephrons and their associated blood vessels.
- Each nephron consists of a single long tubule and a ball of capillaries called the glomerulus.
- The blind end of the tubule forms a cup-shaped swelling, called Bowman's capsule, that surrounds the glomerulus.
  - Each human kidney contains about a million nephrons, with a total tubule length of 80 km.
- Filtration occurs as blood pressure forces fluid from the blood in the glomerulus into the lumen of Bowman's capsule.
  - The porous capillaries, along with specialised capsule cells, are permeable to water and small solutes but not to blood cells or large molecules such as plasma proteins.
  - The filtrate in Bowman's capsule contains salt, glucose, amino acids, vitamins, nitrogenous wastes such as urea, and other small molecules.
  - Because filtration of small molecules is nonselective, the mixture mirrors the relative concentrations of solutes in blood plasma.
- From Bowman's capsule, the filtrate passes through three regions of the nephron: the proximal tubule; the loop of Henle, a hairpin turn with a descending limb and an ascending limb; and the distal tubule.
- The distal tubule empties into a collecting duct, which receives processed filtrate from many nephrons.
- The many collecting ducts empty into the renal pelvis, which is drained by the ureter.
- In the human kidney, about 85% of the nephrons, the cortical nephrons, have reduced loops of Henle and are almost entirely confined to the renal cortex.
- The other 15%, the juxtamedullary nephrons, have well-developed loops that extend deeply into the renal medulla.
  - It is the juxtamedullary nephrons that enable mammals to produce urine that is hyperosmotic to body fluids, conserving water.
- The nephron and the collecting duct are lined by a transport epithelium that processes the filtrate to form the urine. Their most important task is to reabsorb solutes and water.
  - The nephrons and collecting

ducts reabsorb nearly all of the sugar, vitamins and other organic nutrients from the initial filtrate and about 99% of the water.
    - This reabsorption reduces 180 L of initial filtrate to about 1.5 L of urine to be voided.
- Each nephron is supplied with blood by an afferent arteriole, a branch of the renal artery that subdivides into the capillaries of the glomerulus.
- The capillaries converge as they leave the glomerulus, forming an efferent arteriole.
- This vessel subdivides again into the peritubular capillaries which surround the proximal and distal tubules.
- Additional capillaries extend downward to form the vasa recta, a loop of capillaries that serves the loop of Henle.
- The tubules and capillaries are immersed in interstitial fluid, through which substances diffuse.
- Although the excretory tubules and their surrounding capillaries are closely associated, they do not exchange materials directly.
- The tubules and capillaries are immersed in interstitial fluid, through which various materials diffuse between the plasma in the capillaries and the filtrate within the nephron tubule.
- The vasa recta and the loop of Henle function together as part of a countercurrent system that enhances nephron efficiency.

The kidney and homeostasis

Activity 4.17: To examine the external and internal structure of a mammalian kidney

Requirements

- Fresh kidney of sheep, goat or cow
- Sharp razor, knife or scalpel
- Small dissecting board
- Hand lens or dissecting microscope

Procedure

1. Examine the whole kidney. Note the various tubes attached to it.

   What is the outer colour of the kidney?
2. Draw and label the external structure of the kidney.
3. Place the kidney on the dissecting board.
4. Use the scalpel to cut the kidney along its length at the middle.
5. Identify the following parts: cortex, medulla, pelvis, renal artery, renal vein and urethra.
6. Draw and label the internal structure of the kidney.

Study questions

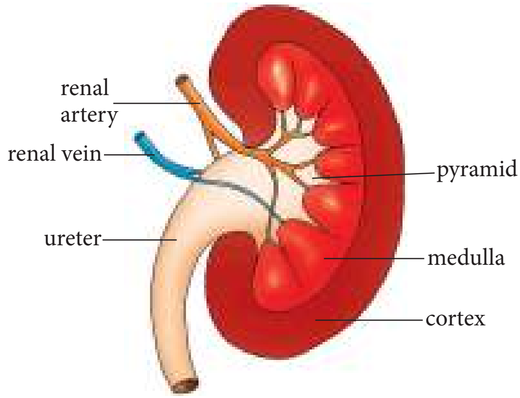
1. What are nephrons?
2. How are nephrons structured?
3. What is the function of the nephrons?

Kidneys are bean-shaped and are red-brown in colour. They lie near the back of the abdominal cavity about the level of the waistline. Each kidney weighs approximately 142.5g. It is about the size of a clenched fist. The right kidney is slightly lower than the left. The kidney is surrounded by a layer of fat which helps to cushion it from mechanical or physical injury.

The kidney is supplied with blood from the general circulatory system via the **renal artery** which branches off from the aorta. Blood from the kidney goes back to the general circulation through the **renal vein** which joins the vena cava. A tube called the ureter connects each kidney to the bladder located in the lower abdomen. The bladder is stretchy to hold large quantities of urine. It stores urine temporarily. From the bladder, another tube called the urethra opens to the exterior of the organism. Two rings of sphincter muscles encircle the urethra. They control the emptying of the bladder.

Internal structure of the kidney

A frontal section through the kidney reveals three main regions. The outer part called **cortex**, inner part called **medulla** and the **pelvis**.



4.10: The cross-section of the kidney

1. Cortex

This is the outer part which is dark in colour. It contains a dense network of blood capillaries that form the **glomeruli of nephrons**. These are the functional units of the kidney.

2. Medulla

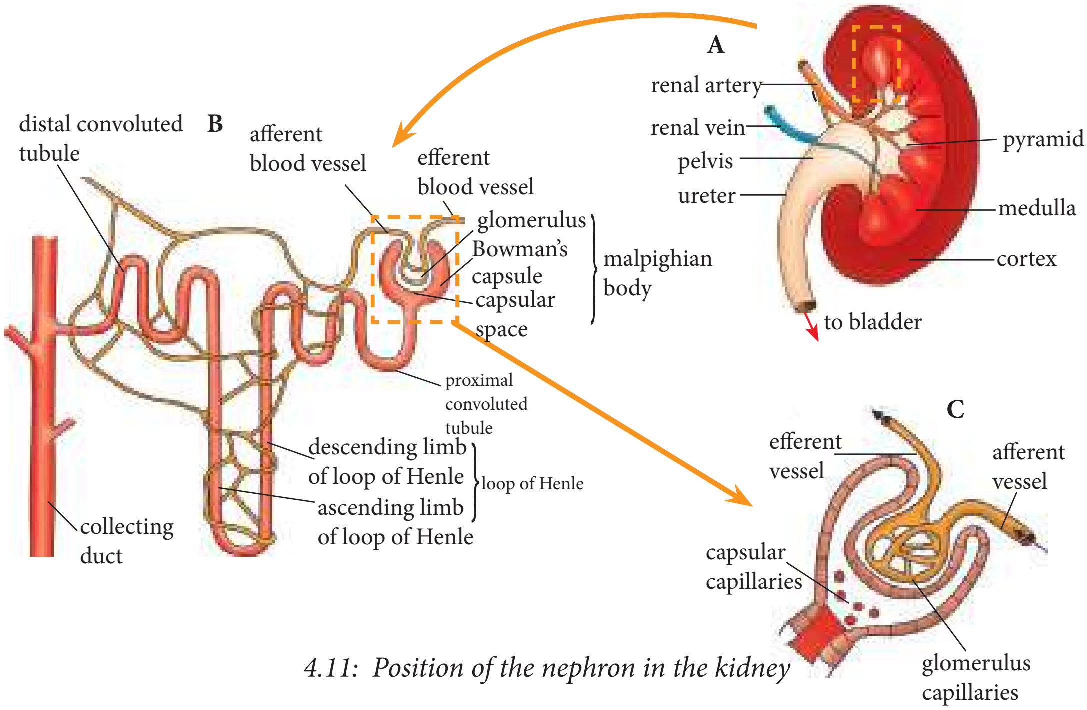
This part is pale red in colour and lies between the cortex and the pelvis. It contains several cone-like extensions called **pyramids.**

3. Pelvis

This part is white in colour. It narrows to form the ureter. Pelvis is a collecting space leading to the ureter, which takes urine to the bladder.

The nephron

The most important function of the kidneys as an excretory organ is to filter wastes from the blood. This takes place in tiny units called nephrons or renal tubules. A nephron is therefore referred to as the functional unit of the kidney. Each kidney has about 1.25 million nephrons. One part of the nephron is in the cortex and the other part in the medulla.



4.11: Position of the nephron in the kidney

The nephron has three distinct coiled parts:

- The proximal convoluted tubule
- A U-shaped loop of Henle
- A distal convoluted tubule

Both the proximal convoluted tubule and the distal convoluted tubule are located in the cortex. The loop of Henle is in the medulla. One end of the nephron is modified to form a cup-shaped structure called the **Bowman's capsule**.

The nephron is supplied with an extensive network of blood capillaries. In the Bowman's capsule, the capillaries form a knot called the **glomerulus** (plural glomeruli) which branches from an **afferent arteriole** that originates from the **renal artery**. The glomeruli capillaries reunite to form an **efferent arteriole** which channels blood away from the glomerulus.

Thus, on one end of the nephron is blood supply from the artery, and on the other end is blood supply to the vena cava.

Urine formation

Excretion in the nephron is carried out in two stages: **ultrafiltration** and **selective reabsorption**. Blood coming into the kidney from the artery contains both waste substances and useful substances. Both substances must enter the nephron, where separation takes place by **ultrafiltration**. The body must not lose the useful substances. Therefore useful substances must be taken back into the blood so that they are not lost. This process is known as **selective reabsorption**.

(a) Ultrafiltration

Ultrafiltration takes place in the glomerulus.

Note: The afferent arteriole that takes blood to the glomerular capillaries has a wider lumen than the efferent arteriole that takes blood away from it.

Due to the difference in afferent and efferent size, a high pressure of blood is created in the glomerulus. This pressure forces **water, mineral ions** and small molecules like **glucose, amino acids** and **urea** out of the glomerulus. These pass through the tiny pores in the walls of the glomerular capillaries into the Bowman's capsule. The liquid collected in the Bowman's capsule is called **glomerular filtrate**.

The larger molecules in the blood like **blood proteins, white blood cells, red blood cells** and **platelets** cannot pass through the capillary walls of the glomerulus. These remain in the blood and continue to flow to the efferent arteriole. The glomerular filtrate flows down the nephron where re-absorption will take place as it flows along.

(b) Selective reabsorption

As the glomerular filtrate passes along the nephron, some substances that are useful to the body are selectively taken back or reabsorbed into the blood capillaries network surrounding the nephron.

- All **amino acids** and **glucose** are reabsorbed by active transport in the proximal convoluted tubule.
- Some **salts** and **water** are reabsorbed depending on how much of them the body still needs. Water is absorbed by osmosis and salts by active transport. Salts are absorbed mainly in the distal convoluted tubule. Water is reabsorbed in both the proximal and distal convoluted tubules. However, most of the water is reabsorbed in the region of the collecting duct.
- No **urea** is reabsorbed into the blood.

By the time the filtrate from the glomerulus completes its movement down the nephron, it has a high concentration of **urea, some salts** and **water**. The liquid is now called **urine**. Several nephrons empty into one collecting duct, and all the collecting ducts of a kidney empty into the ureter. The process of urine formation is a continuous one, and the ureter continuously receives small amounts of urine. The bladder stores the urine until it is full, then one begins to experience an uncomfortable feeling. The **sphincter muscles** must then be relaxed in order to empty the bladder.

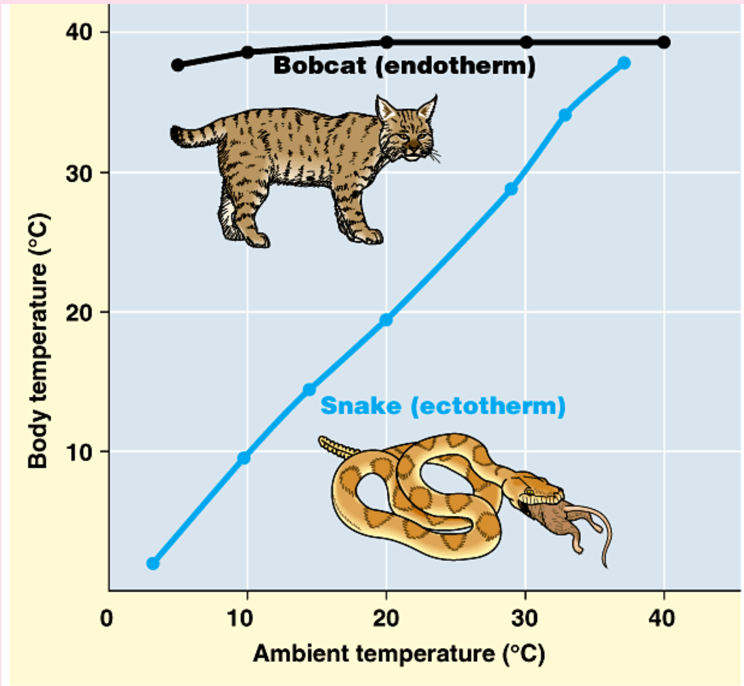
Research project

(Health impact and dialysis)

Using reference materials and the internet, research on kidney donation and explain why donors can survive with only one kidney. Explain also what happens to patients with kidney failure.

Check your progress 4.4

The graph below shows the body temperatures of a bobcat and a snake at different air temperatures.



1. What are the body temperatures of the snake and lion when the air temperature is 15° C?
2. The table below shows how body temperature is regulated by the hypothalamus by influencing heat production and heat loss.

Body temperature °C	Heat production Joules	Heat loss Joules per second
36.4	320	5
36.6	360	5
36.8	150	35
36.9	90	90
37.0	90	100
37.2	90	180
37.4	90	310

a) Are the blood vessels that supply blood to the skin constricted or dilated when the body temperature is 36.4 °C?

b) Explain the advantage of the diameter of the blood vessels(constricted/ dilated) mentioned in your answer to a).

c) Heat loss is greatest at 37.4 °C. Explain how the body is able to increase heat loss.

Unit 5

Genetics and inheritance

Learning outcomes

Knowledge and understanding	Skills	Attitude
• Understand basic genetics and inheritance; modern uses of knowledge of genetics	• Design investigations on genetic crosses, predict outcomes, analyse results and evaluate them in terms of predictions • Develop hypotheses to demonstrate monohybrid inheritance and the concepts of homozygous and heterozygous dominance	• Appreciate the wonder of genetics and inheritance and the beauty of evolution • Rehearse the potential and ethical considerations of genetics

Introduction to genetics and homeostasis

1. Look at the picture below. Count the number of blue, red and yellow marbles in each bottle. How many are they per generation?

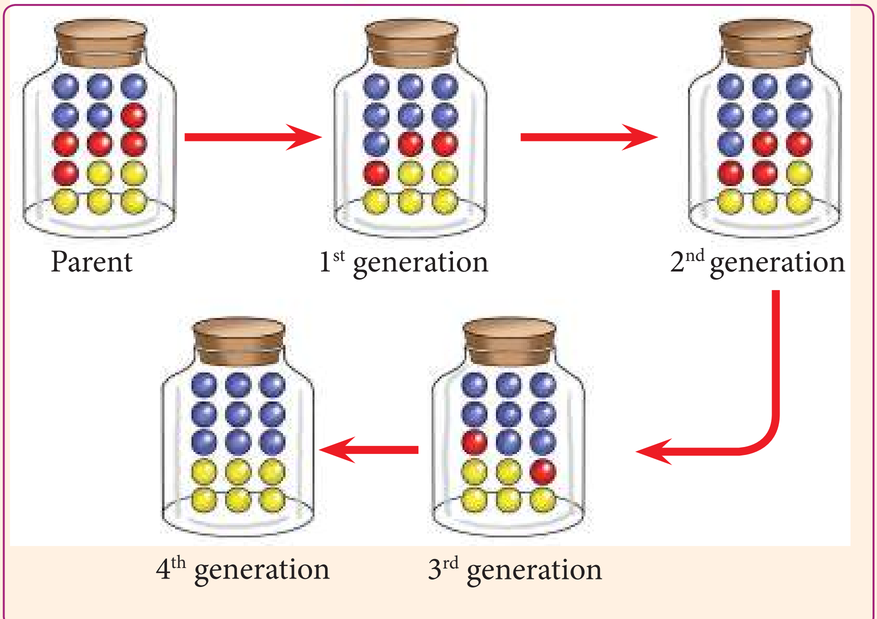


Fig 5.1: Generation representation

2. Assuming that each colour represents a characteristic of an individual, can you note any trend in the characteristics as you move from one generation to another?
3. Where do you think the red characteristic disappeared to in the 4th generation?
4. Why did the number of blue characteristic in the 4th generation increase?
5. Assuming this is how inheritance occurs, what do you think genetics is all about?

The facts

Cells contain chromosomes and genes that determine characteristics and the beads represent these in the brain teaser.

Genetics is a branch of science that deals with the study of inheritance and variation of characteristics in individuals. Heredity is the principle behind inheritance of characteristics. **Gregory Mendel** - an Australian monk who carried out the first ever investigations on inheritance of characteristics. For this reason he is referred to as the 'father of genetics'.

Fig 5.2: Gregory Mendel (1822-1884)

5.1 Inheritance and key terms used in genetics

Activity 5.1: Investigating inheritance and variation

Work in pairs

1. Use the pedigree diagrams provided to trace a given characteristic.
2. With a friend, discuss the following:
   (i) Features of either of your parents that you have and those you have but are not seen in either of your parents.
   (ii) Reasons for the variation observed in characteristics in members of the same family.
3. Do a survey in class and fill the following table. Use (✓) or (×)

Table 5.1: Characteristic traits

Traits	✓	×
Detached ear lobes		
Tongue rolling		
Black skin colour		
Brown skin colour		
Have allergies		
Use left hand		

4. Present your work to the rest of the class.

Activity 5.2: To investigate variation in tongue rolling ability among members of class

Work as a class.

Procedure

1. Let the members of your class try and roll their tongue to form a U-shape.
2. Count the number of students in the class that:
   a) Are able to roll their tongue.
   b) Are unable to roll their tongue.
3. Fill your results in a table as shown below.

Table 5.2 Result of rollers and non-rollers

Rollers		
Non-rollers		
Total		

4. Calculate the percentage of students i.e. those who are able to roll their tongue and those who are not able to roll their tongue.

Study questions

(i) How many students had the ability to roll their tongue?

(ii) How many students were unable to roll their tongue?

(iii) Were there students who could not fall in either of the groups?

(iv) Suggest another characteristic in your class members that can put them into distinctions.

The facts

From Activity 5.2, you may have found out that the students in the class can be put into two groups according to their ability to roll their tongue. One group was able to roll their tongue while the other group was unable to roll their tongue. Also, you may have noticed that there are no students in between the two groups i.e. students who could roll their tongue halfway. In this case, each student was either a roller or a non-roller.

The characteristic of tongue rolling therefore has two variations that are distinct from each other. This is referred to as **discontinuous** variation. Another characteristic that has two distinct variations is gender. Discontinuous variation is caused by genetic factors called genes found in the nucleus of the cell. The genetic factors are inherited by the offspring from the parents.

The transmission of genetic information from generation to generation is known as **inheritance**. Genes are the "vehicles" of inheritance and are responsible for the appearance of an organism. Genes are arranged in a specific sequence along each chromosome. Mendel used garden pea, *Pisum sativum,* in his experiments to determine how characteristics were transmitted from parents to offspring through what he called *factors*. These were later called **genes**.

Common terms used in genetics

To understand Mendel's findings, it is first important to know some genetical terms.

Gene refers to a portion of DNA that is responsible for synthesis of a polypeptide (protein). They are the unit of heredity that is transferred from a parent to offspring and is held to determine some characteristic of the offspring.

Trait is the characteristic shown by an organism i.e. the characteristic of an individual e.g. red, tall, blood group etc.

Chromosomes are threadlike structures of nucleic acids and protein found in the nucleus of most living cells, carrying genetic information in the form of genes.

Some characteristics show variation in species. For example, in dogs, the skin fur could be white, black or brown. A different gene determines each colour. These genes determine variation in the same characteristic and are therefore found on the same loci or position on the homologous chromosomes. Such genes are referred to as **alleles.** An allele is a short form of allelomorph, which comes from two Greek words "allele" and "morphe" meaning "each other" and "form" respectively. Therefore, the word allele means **different forms of the same gene.**

It is important to note that each characteristic is represented in the cell by alleles that always occur in pairs. These pairs of alleles in the homologous chromosomes can be the same or different.

A **dominant allele** is the allele that influences a characteristic to develop in an individual over another allele.

A recessive allele is the one that cannot influence a characteristic to develop in an individual in the presence of the dominant allele. The dominant allele is usually represented by a *capital letter* while the recessive allele is represented by a *small letter***.**

The particular set of alleles in each cell determining a given characteristic is referred to as the **genotype**. This is also referred to as the **genetic composition** of an organism for that specific characteristic.

Genotype is the genetic constitution or genetic make up of an organism. The genotype influences the development of physical characteristics in an individual. The genotype is always denoted by use of letters. The letters used are in 'twos' or in 'pairs'. For example, BB, Bb or bb are three different genotypes. In the example above, the alleles were denoted by B and b.

As such, from the example above, the possible genotypes are **BB, bb** and **Bb.** When two alleles in a genotype are similar, the individual is said to be **homozygous** or **true breeding** to that particular characteristic. For instance, if the genotype is BB, the individual is **homozygous dominant,** if the genotype is bb, the individual is said to be **homozygous recessive**.

If the two alleles are different, the individual is said to be **heterozygous** for that particular characteristic. If the individual has genotype Bb, the individual is said to be heterozygous for that particular characteristic.

Phenotype is the outward or physical appearance of an organism. It is determined by the inheritance of the genes and the environment e.g. tall, short, brown, round etc. The phenotype of an individual is expressed in words.

Black fur and white fur are examples of phenotypes. Table 20.3 gives the difference between genotype and phenotype.

Table 5.3: Genotype and phenotype

Genotype	Phenotype
BB	Black
Bb	Black
bb	White

Locus is the exact position or location of a gene on a chromosome. The plural of the word locus is loci.

Haploid refers to half the number of chromosomes in the body cell. Haploid cells are produced in the gonads i.e. ovaries and testes. The haploid cells include the sperms and eggs (ova).

Diploid refers to the nucleus of a cell that has its chromosomes in the homologous pair. Diploid cells include all the somatic (body) cells. They are formed by the process of fertilisation and denoted as 2n. Mitosis maintains the diploid state of an organism.

First generation refers to the offsprings that are produced after crossing the parental genotypes. It is abbreviated as F1 generation.

Second generation refers to the offspring produced by the crossing of the F1 generation. It is abbreviated as F2 generation.

Hybrid refers to the offspring produced by crossing two individuals with contrasting characteristics.

Parents are individuals that form the starting point of a breed. A cross between parents produces an offspring.

Pedigree is a historical or ancestral record of individuals shown in a chart, table or diagram.

Check your progress 5.1

1. The passing of genes from parents to offspring is ________________.
2. What is the physical structure in a cell that contains genetic information?
3. A diagram that shows the different possible ways in which gene from parents combine is ________________.
4. How many homologous pairs of chromosomes are present in a human body cell?
5. Differentiate between first generation and second generation.
6. Which one of the following statement is FALSE?
   - A. Phenotype is the outward or physical appearance of an organism.
   - B. Locus is the exact position or location of a gene on a chromosome. The plural of the word locus is loci.
   - C. Diploid refers to half the number of chromosomes in a body cell.
   - D. Each characteristic of an individual is represented in the cell by alleles that always occur in pairs.

5.2 Monohybrid inheritance

Activity 5.3: Modeling genetic crosses

Work in pairs

Requirements

- Beads of two colours e.g. 20 red and 20 black
- Five jars
- Plasticine

Procedure

1. Take the two jars in one place 20 red beads. In the other place 20 black beads. The 20 beads represent 10 pairs of alleles in a pure parent.

   Note: Each jar represents a pure parent, pure because each has only one of the two possible types of alleles for a particular genetic characteristic. All pure parents are homozygous; alleles in a pair are similar.

2. Put the two jars one to the right and one to the left.
3. Pick a bead at a time from each jar. Put them together to form a pair. You can also stick them together using plasticine. Place them in one empty jar. Count the pairs formed and the combination.

   Note: As we take beads from each jar and combine them, we are modelling what would happen if these two parents were to reproduce. In the pair formed all will be 10 pairs each made of one black bead and one red bead.

   This represents the F1 generation. It is composed of offspring with one dominant gene and one recessive gene hence heterozygous.

4. Divide the mixed beads into two halves and put them in two separate jars. Make sure each jar has 10 red beads and 10 black beads. These two jars represent two parents in F1 generation.
5. Place one to the right and one to the left.
6. Pick one bead at random without looking from each jar at a time. Observe the beads picked. Place them together on a table. If both are black place them on one jar labelled **X**. If one is black and one is red place them on a second jar labelled **Y**. If both are red, place them on a third jar labelled **Z**. Repeat the picking until all the beads from the two jars are picked.
7. Count the number of pairs in X, Y and Z.
8. Record them in a table as shown below.

Table 5.4: Genetic crosses

Set	Number of pairs
X-black pairs	
Y-black and red pairs	
Z-red pair	

Study questions

1. Calculate the ratio of X, Y and Z.
2. Calculate the ratio of X added to Y to that of Z i.e. (X, Y)

The facts

Mendel's first experiments involved monohybrid crosses only. In this case, he studied the inheritance of only **one pair of contrasting characteristics**.

Mendel chose to study each of these characteristics. He selected one characteristic of the plant at a time. He started by identifying groups of plants that were pure lines or true breeding homozygous plants. These were plants which when allowed to self-pollinate, could only produce an offspring identical to themselves hence true breeding. For instance, if the parent plant was tall and was allowed to self pollinate, all the offspring produced were tall. All pure lines are homozygous to a given characteristic. For example, pure tall plant have genotype **TT** meaning it is homozygous dominant.

Pure line dwarf plant has a genotype **tt** meaning it is homozygous recessive. He cross pollinated the two plants. This resulted in **fertilisation.** The process of fertilisation is also referred to as **crossing.** The fertilisation process that was involved is as shown in the following cross diagram.

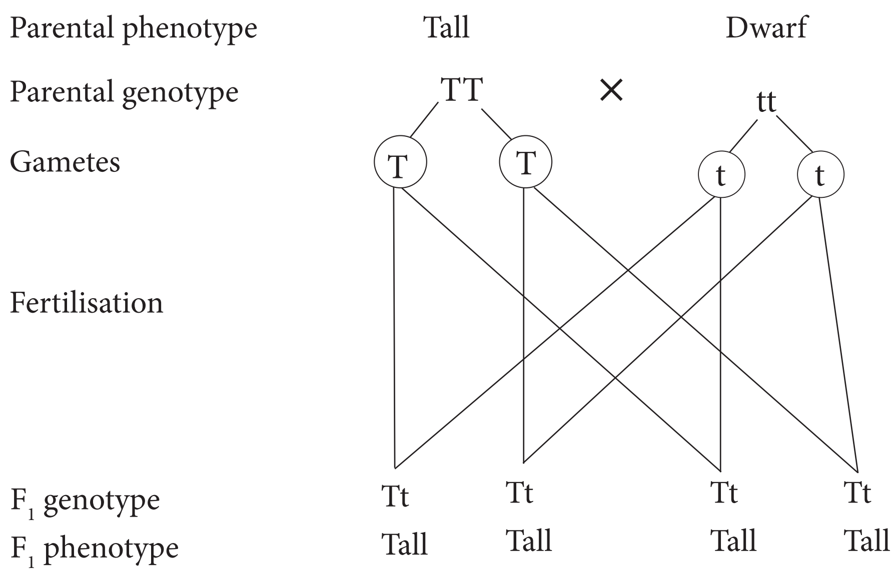


Fig 5.3: Crossing of genotypes

Fact of life: All gametes must be circled.

He allowed the fertilised flowers of the dwarf plant to produce seeds. He then planted these seeds, allowed them to grow and develop into new plants. These plants are referred to as the **F1 generation plants.** F1 stands for the first filial generation. The word "Filial"means offspring and so F1 means the first offspring. He noted that all the plants in the F1 generation were tall. He concluded that on crossing a pure tall plant with a pure dwarf pea plant, an F1 generation that was composed of only tall pea plants was produced.

The reason for this was that the offspring had obtained a dominant allele for tallness and a recessive allele for dwarfness giving a heterozygous genotype **Tt**. This resulted in plants that were phenotypically tall.

Mendel then allowed the flowers of F1 generation plants to undergo self-pollination and fertilisation. He took the seeds produced and planted them to get the second Filial (F2) generation. The fertilisation that resulted in the F2 generation is illustrated in the cross diagram below.

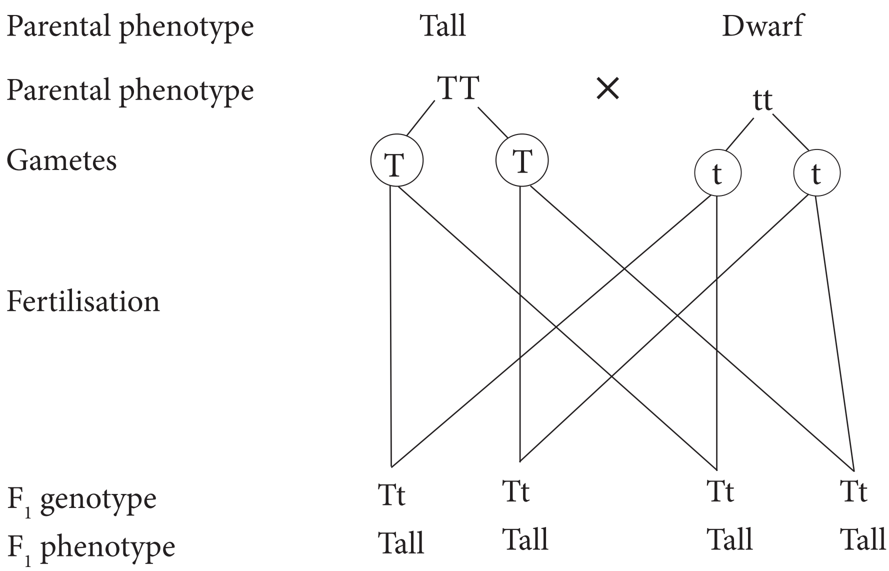


Fig 5.4: F2 generation crossing of genotypes

He noted that the F2 generation pea plants were composed of tall pea plants and dwarf plants. On counting, he noted that the number of tall plants were approximately 3 times the number of dwarf plants. For example, in one field, the tall plants were 787 while the dwarf plants were 277. This gives a ratio of approximately 3:1 of the tall to dwarf plants. The example given above is typical of all Mendel's experiments involving the inheritance of a single characteristic. This inheritance is referred to as **monohybrid inheritance.**

The genotypic ratio is the ration of all the different genotypes of the four possible offspring produced. These are in our case TT, Tt, Tt, tt. The ratio is written as 1TT : 2Tt : 1 tt.

The phenotypic ratio is the ratio of the different phenotypes in the four possible offspring produced. These, in our case above, are Tall, tall tall and dwarf.

The phenotypic ratio is written as 3 Tall : 1 Dwarf.

The crosses above can also be illustrated by use of a table known as the **Punnet square** to predict possible genotypes and phenotypes of offsprings. It involves use of a table with rows and columns. The first row and first column of the table are used to give information on the distribution of genes in the gametes of the parents as shown in the table below.

Table 5.5: Punnet square

Female gamete / Male gamete	Genes/ Alleles	Genes/ Alleles
Genes/Alleles		
Genes/Alleles		

Table 5:6 Punnet square for tall and dwarf plants

For example, if we consider the cross between the tall and dwarf plant discussed earlier, the Punnet square would look like the one shown below.

	Female	Male
Parental phenotype	Tall	Dwarf
Parental genotype	TT	Tt

Female genes/alleles Male genes/ alleles	T	t
T	Tt	Tt
T	Tt	Tt

F1 generation genotype – Tt for All
F1 generation phenotype – All Tall

Did you know?

The genotype and phenotype of the parents are indicated above the punnet square and those of the offspring below the punnet square.

Check your progress 5.2

1. State Mendel's first law of hereditary.
2. State the correct science vocabulary term that fits each of the following definitions.
   (i) The offspring of a cross between pure breeding parents.
   (ii) A cross in which only one pair of contrasting characteristics are studied.
   (iii) A type of inheritance in which neither of the pair of alleles is dominant to the other so both phenotypes appear in the offspring.
3. In a certain species of mice, black coat colour is dominant over white coat colour. If two heterozygous black mice are mated, the phenotypic ratio would probably be:
   A. 3:1 B. 1:2:1
   C. 1:3 D. 3:3:1
4. In short horned cattle, the allele for white coat and the allele for red coat are both dominant. A cross between a red bull and a white cow produces roan calves. If two roan cattle are mated, which percentage of their offspring will probably have white coat?

A.	50%	B.	25%
C.	75%	D.	100%

5. In pea plants, the allele for tallness (T) is dominant over the allele for shortness (t). Using a punnet square:
   a) Determine the genotype of offspring of a cross between a hybrid and short plant.
   b) State the genotypic and phenotypic ratios.

5.3 Hybrid and test cross

A **hybrid** is an offspring that is produced after a cross of two pure line parents. The hybrid obtains the dominant genes from both parents, making it have characteristics determined by dominant genes from both parents.

A farmer wanted to breed white rabbits only for sale. He selected two white rabbits as parents for breeding. He then crossed the parents. To his dismay, some of the rabbits in the litter produced were black and he could not sell them. If the allele for white fur is dominant over the allele for black fur, how would the farmer ensure that only parents that produce white rabbits all the time were used?

Note that the genotype for the white rabbits could either be homozygous dominant (BB) or heterozygous (Bb). By merely looking at the rabbits, the farmer will not know their genotypes. To breed white rabbits only all the time, the genotype of the parents need to be known. In this case, he would need to know that in order to produce all white offsprings, two homozygous parents would be required. In selecting these parents, he would first need to determine their genotypes before crossing them. This method of determining the unknown genotype is known as a **test-cross** or **back cross**. It is carried out by crossing the organism whose genotype is unknown with a **homozygous recessive** organism for that particular genotype. Back cross means a test cross whereby one parent is crossed with an offspring.

If no offspring with homozygous recessive genotype is produced, then it is concluded that the parent whose genotype is unknown does not have a recessive allele. Therefore, the parent is homozygous dominant.

If some offspring have the recessive trait, this means that the parent whose genotype is unknown has a recessive allele. Therefore, the parents' genotype is heterozygous.

Consider the example above. The farmer would carry out the test cross to determine the unknown genotype of the white rabbit by crossing the white rabbit with a black rabbit which has a homozygous recessive genotype.

The white rabbit with the unknown genotype can be genotypically homozygous dominant (WW) or heterozygous (Ww). The possible outcomes of the crosses are as shown on the next page.

(a) If the unknown genotype is heterozygous dominant (Ww). Let W represent the allele for White colour and w represent the allele for black colour.

Parental phenotype	White rabbit			Black rabbit
Parental genotype	Ww	x		ww
Gametes	W	w	w	w
Random fertilisation				
F_1 generation genotype	Ww	Ww	ww	ww
F_1 generation phenotype Phenotypic ratio 1:1	White rabbit	White rabbit	Black rabbit	Black rabbit

The presence of black rabbits amongst the offsprings indicates the presence of a recessive allele in both parents. This shows that the genotype of the white rabbit is heterozygous (Ww).

(i) Determination of F_1 generation

We will use the results in Mendel's experiments to make these crosses.
Let T represent the allele for tallness and t represent the allele for dwarfism.

Parental phenotype	Tall	x		Dwarf
Parental genotype	TT	x		tt
Gametes	T	T	t	t
Random fertilisation				
F_1 genotype	Tt	Tt	Tt	Tt
F_1 phenotype	Tall	Tall	Tall	Tall

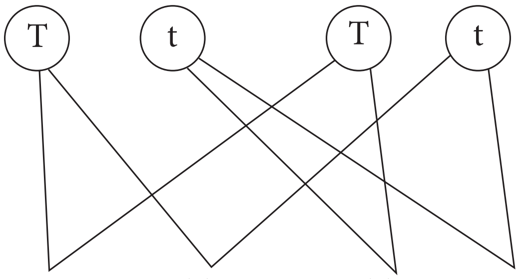
(ii) Determination of F_2 generation

This is done by selfing the offspring in the F_1 generation. Selfing means that the individuals in F_1 generation are grown and self fertilised.

Parental phenotype	Tall	x	Tall
Parental genotype	Tt	x	Tt

Gametes: T t T t

Random fertilisation



F_2 genotype	TT	Tt	Tt	tt
F_2 phenotype	Tall	Tall	Tall	Dwarf

The phenotypic ratio in F_2 is

3 tall : 1 dwarf

3:1

The genotypic ratio in F_2 is

1 TT :2 Tt :1 tt

1:2:1

The crosses above can also be illustrated by use of a table known as a **Punnet square** to predict possible genotypes and phenotypes of offsprings. It involves use of a table with rows and columns.

The first row and first column of the table are used to give information on the distribution of genes in the gametes of the parents as shown in Table 5.7.

Table 5.7: Punnet square

Female gamete / Male gamete	Genes/ Alleles	Genes/ Alleles
Genes/Alleles	Tt	Tt
Genes/Alleles	Tt	

For example, if we consider the cross between the tall and dwarf plant discussed earlier, the Punnet square would look like the one shown below.

Table 5.8:

	Female	Male
Parental phenotype	Tall	Dwarf
Parental genotype	TT	tt

Female gamete / Male gamete	T	T
t	Tt	Tt
t	Tt	

F_1 generation genotype – Tt for Tall

F_1 generation phenotype – All Tall

Genotypic ratio: 1TT: 2Tt:1tt

Phenotypic ratio: 3 Tall: 1 dwarf

Note that the genotype and phenotype of the parents are indicated above the punnet square and those of the offspring below the punnet square. The genotypic and phenotypic ratios are also indicated.

5.4 Complete dominance, incomplete dominance and co-dominance

Activity 5.4: Discussion Activity

1. With a classmate discuss the following:
   a) The difference between complete dominance, incomplete dominance and co-dominance.
   b) ABO blood group.
   c) Can blood group type be used in paternal dispute?
2. Compare your findings with the rest of the class.

The facts

We have learnt that when two alleles are present in a heterozygous state, the dominant allele is the one that expresses itself in the phenotype. Such allele determines the outcome of the phenotype of the individual whereas the recessive allele will not express itself. The recessive allele will have no effect on the outcome of the phenotype of the individual. This is what is called **complete dominance.**

For example in Mendel's experiments, we found out that when a pure tall pea plant is crossed with a pure dwarf plant, an F1 generation of tall pea plants is produced. In this generation, we find that only the allele for tallness influence the phenotype. The allele for dwarfness does not influence the phenotype. Therefore, the allele for tallness is completely dominant over the allele for dwarfness. However, in certain cases, two alleles present in a heterozygous state may both express themselves in the phenotype. Such alleles determine the outcome of the phenotype of the individual. This is known as **incomplete dominance.**

For instance, flower colour of the snap dragon plant. The plant has two alleles one for production of red flower pigmentation and the other for production of white flower pigmentation. When the two alleles are found together in a heterozygous state, both red and white pigments are produced. The flower colour is neither red nor white, but a mixture or intermediate of the two colours, which is pink.

This shows that the two alleles show incomplete dominance. Such alleles are denoted by using different capital letters.

Co-dominance on the other hand is a condition in which both alleles of a gene pair in a heterozygote are fully expressed, with neither one being dominant or recessive to the other. Example of co-dominance is seen in the inheritance of ABO blood groups.

The inheritance of the ABO blood group is determined by three alleles (multiple alleles) that influence formation of antigens on the red blood cells. These alleles are Allele A, Allele B and Allele O.

- Allele A determines the formation of Antigen A on the red blood cells.
- Allele B determines the formation of antigen B on the red blood cells
- Allele O prevents the formation of antigen A and antigen B on the red blood cells in their homozygous forms.

Alleles A and B show incomplete dominance to each other yet both are dominant to allele O. In other words, allele O is recessive to alleles A and B.

The alleles as we learnt earlier are always found in pairs in the homologous chromosomes. These alleles can occur in the following combinations which represent the possible genotypes of the individuals. These are AA, AB, AO, BB, BO, and OO.

- If the genotypes are AA or AO only, antigen A is formed. The individual has blood group A. If the genotypes are BB or BO only antigen B is formed. The individual has blood group B.
- If the genotype is AB, both antigen A and B are formed, the blood group is AB. Allele A is co-dominant with allele B.
- If the genotype is OO, neither antigen A nor antigen B are formed. The blood group is O. Allele O is recessive to allele A and B.

Table 5.9:The relationships between genotypes in blood group

Possible genotype	Antigen formed on red blood cell	Blood group
AA	A	A
AO	A	A
BB	B	B
BO	B	B
AB	A and B	AB
OO	None	O

Note: The blood groups are considered to be the phenotypes of the genotypes involved.

The ABO blood group system exhibits four phenotypic blood groups that are controlled by three alleles which are represented as IA, IB and IO. There are six possible genotypes for the ABO blood group system.

Table 5.10: Genotypes for ABO blood groups

Genotypes	Phenotypes (Blood group)
IA IA	A
IA IO	A
IB IB	B
IB IO	B
IA IB	AB
IO IO	O

The inheritance of the ABO blood group alleles follows the normal Mendelian fashion. For instance, if a man who is homozygous for blood group B, genotype IB IB, marries a woman who is blood group O, genotype IO IO, all their children will have blood group B.

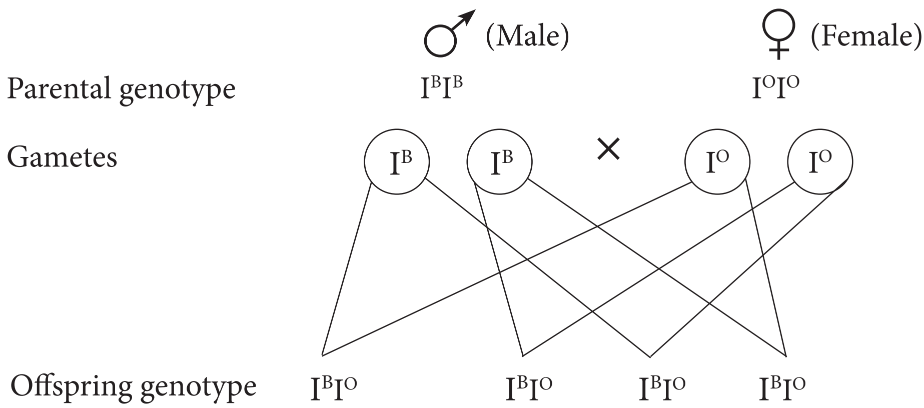


Fig 5.5: Cross diagram for blood groups

Check your progress 5.3

1. A woman gave birth in a hospital but there was a problem identifying their child. Both the woman and the husband think their child has been switched for another. If the woman is blood group B and the man blood group A, use genetic crosses to support or disagree with their allegations given that their child is blood group O. (Use the symbols IA, IB, IO)
2. A man who is blood group A marries a woman who is blood group B. If one of their children is blood group O, use a punnet square to determine the genotype of the other children.
3. Incomplete dominance is also known as _______.
   A. co-dominance
   B. dominance
   C. segregation
   D. blending inheritance
4. Name two antigens that determine blood groups in human beings.
5. What type of dominance is portrayed in the inheritance of blood group:
   a) AB?
   b) A?
6. Use a punnet square to get the probable blood group of the offspring born to the following parents: a father of blood group AB and a mother of blood group O.

5.5 Genetic material

In the previous section, we defined chromosomes as threadlike structures of nucleic acids and protein found in the nucleus of most living cells which carry the genetic information in form of genes. In this sub-unit we will look in detail in order to understand how replication and inheritance occurs.

There are two types of genetic materials namely DNA (Deoxyribonucleic Acid) and RNA (Ribonucleic Acid).

The DNA has information coded in it that dictates the characteristics of the offspring, for example short or tall and male or female. During sexual reproduction, it is the nucleus of the male gamete that fuses with the nucleus of the female gamete.

This shows that the character-determining factors are found in the nucleus. In the nucleus, there are thread-like structures called ***chromosomes***. Chromosomes contain protein structures called ***genes*** that carry the genetic material.

Chromosomes

Chromosomes are thread-like structures found in the nucleus of the cell. Chromosomes contain the genes. Chromosomes are only visible when a cell nucleus is about to divide. Every nucleus of a cell of the same species has a constant number of chromosomes. For example, a human body cell has 46 chromosomes, fruit fly (*Drosophila*) has 8 chromosomes, a garden pea plant has 14 chromosomes, maize has 20, sheep has 56 and wheat 14. Each chromosome is made up of two parallel strands known as ***chromatids*** (Fig 5.6).

The two chromatids are connected to each other at a certain point by a structure called ***centromere*** (Fig 5.6). Chromosomes occur in pairs. The two chromosomes that form the pair have the same length and look alike but may be different in their genetic composition. Each member of the pair is known as ***homologous chromosome***. During sexual reproduction, each parent contributes one of the chromosomes from each homologous pair.

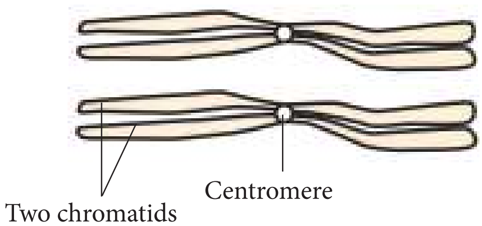


Fig. 5.6: A pair of homologous chromosomes

There are two types of chromosomes in a human body cell nucleus. These are **autosomes** and **heterosomes**.

(a) Autosomes

These are also known as ***autosomal chromosomes***. They carry all the genetic information except that of sex. In humans, the autosomes are 44 in number forming 22 pairs.

(b) Heterosomes

These are also known as ***sex chromosomes***. These chromosomes determine the sex of the organism. In humans, there are two sex chromosomes forming one pair. These two sex chromosomes are called **X** chromosome and **Y** chromosome. They will be discussed later in this chapter.

Diploid and haploid nuclei

Diploid nuclei have the chromosomes occurring as a homologous pair. For example, 23 pairs in humans. This is denoted as **2n** where **n** stands for the number of pairs.

Diploid nuclei are found in body (somatic) cells of animals and in vegetative cells of flowering plants. Haploid nuclei have only one set of unpaired chromosomes, for example 23 chromosomes in humans. This is seen in the gametes (sperms and eggs) and in spores of algae, liverworts and mosses. Haploid nuclei are denoted as **n**. Haploid cells are formed after meiosis. Diploid cells are formed after fertilisation.

Genes

A gene is a sequence of DNA or RNA that codes for a molecule that has a function (Fig 5.7). Each gene occupies a specific location on a chromosome. This location is known as ***locus*** (plural is loci). Each chromosome contains many genes. Over 800 different genes have so far been identified on the 46 human chromosomes.

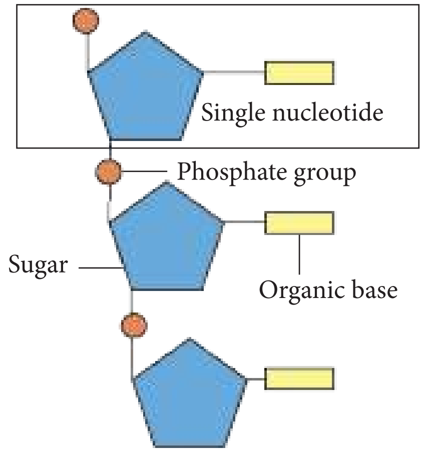


Fig. 5.7: Structure of a nucleotide

Homologous chromosomes when paired together will have similar or different genes which are called ***alleles.*** An allele is an alternative form of a gene, controlling the same character but producing a different effect.

DNA

DNA is the genetic material contained in the genes. DNA means ***Deoxyribonucleic acid.*** It has a double stranded shape or coil twisted like a ladder to form a double helix.

Components of DNA

The componets of DNA molecule are ***deoxyribose sugar, five carbon sugar (pentose), phosphate group*** and ***organic base*** (Fig 5.8).

The organic bases are usually nitrogenous bases. There are four nitrogenous bases namely Adenine (A), Guanine (G), Cytocine (C) and Thymine (T).

The quantities of ***Adenine*** and ***Thymine*** are the same while that of ***Guanine*** and ***Cytosine*** are also the same. Therefore, these bases combine in such a way that Adenine pairs with Thymine while Guanine pairs with Cytosine.

These bases are held together by weak hydrogen bonds. A combination of a deoxyribose sugar, phosphate group and an organic base forms a ***nucleotide***. DNA is made up of several nucleotides and hence is said to be a polynucleotide. In the DNA molecule, the sugar alternates with the phosphate.

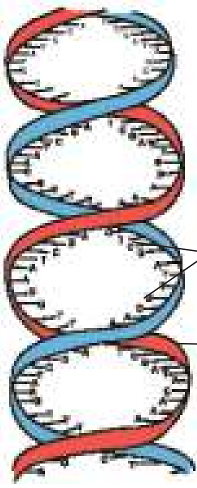


Fig 5.8: Double helix structure of the DNA

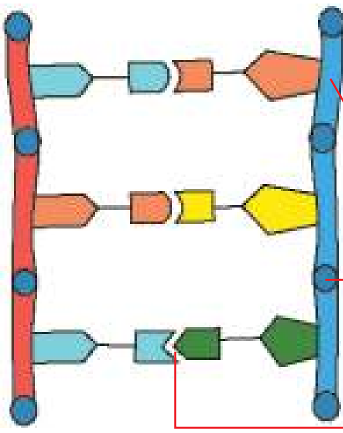


Fig. 5.9: Untwisted DNA strand

DNA replication

The DNA has the ability to replicate itself. This is to provide sufficient genetic material that is to be passed on to the next generation. The double helix consists of two separate strands joined together by the pairs of bases (Fig 5.10). During replication, the weak hydrogen bonds between bases break causing the two strands of the DNA molecule to separate.

The double helix unwinds and the two strands form complementary strands (Fig 5.10). The base sequence is copied out into a new DNA structure using the parent DNA as the template. Thus, the DNA molecule is said to have replicated itself. The DNA molecule replicates at interphase stage of the cell division to provide sufficient DNA for each of the daughter cells.

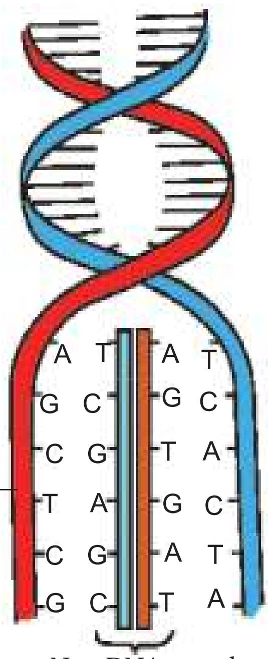


Fig 5.10: DNA replication

Role of DNA in protein synthesis

The DNA of a gene controls protein synthesis. Assembling the amino acids forms a protein molecule. Amino acids are held together by the ***peptide bond***. The DNA dictates the type of amino acid and the sequence in which they are arranged. The DNA therefore controls the production of structural proteins such as muscles and bones or functional proteins such as enzymes, hormones and antigens.

The DNA acts as a code that spells out the sequence of amino acids when they join to form a ***polypeptide chain*** of protein. Along the DNA are three bases that are responsible for bringing into position a particular amino acid. A set of three bases (base triple) is called a ***codon***, and is said to code for a particular amino acid of a protein molecule. For example **AAA** codes for an amino acid called ***phenylalanine***. **TTT** for ***lysine***, **CAA** for ***valine*** and **CTA** for ***aspartic acid***.

RNA

The RNA (ribonucleic acid), like the DNA, is a nucleic acid molecule. RNA has no Thyamine as an organic base but instead has Uracil. Protein synthesis takes place in the ribosome found in the cytoplasm. DNA is confined to the cell nucleus in the chromosomes. Therefore there has to be a means of communicating the DNA information to the ribosome where protein synthesis occurs. The RNA molecule is responsible for carrying genetic information from the DNA molecule inside the cell nucleus to the ribosome, which is the site of protein synthesis in the cytoplasm.

Types of RNA

There are two types of RNA, namely messenger RNA and transfer RNA.

1. Messenger RNA (m – RNA)

It consists of a single strand of nucleotides whose bases are complementary to those of the template DNA from which the mRNA molecule was transcribed. The double helix of the DNA unzips and free nucleotides align themselves opposite the template.

The base sequence of the template is copied into the new strand forming an RNA strand. In RNA, Thymine (T) is replaced by Uracil (U). This transfer of DNA base sequence into the mRNA is called ***transcription***. The mRNA then leaves the nucleus with information in the form of base triplets (codons) of the kind of amino acid to be assembled on the polypeptide chain of proteins. Three codons **UAA**, **UGA** and **VAG** do not specify for any amino acid and are called ***nonsense*** or ***termination codons.***

2. Transfer RNA (tRNA)

The tRNA is synthesised from the DNA molecule in the nucleus. It is responsible for assembling the amino acids into the polypeptide chain. A tRNA has three paired bases at one end forming an ***anticodon*** which corresponds to the mRNA codons (Fig 5.11). The other end becomes attached to its particular amino acid. The tRNA therefore transfers the appropriate amino acids to the ribosome and aligns them with respect to the mRNA codons.

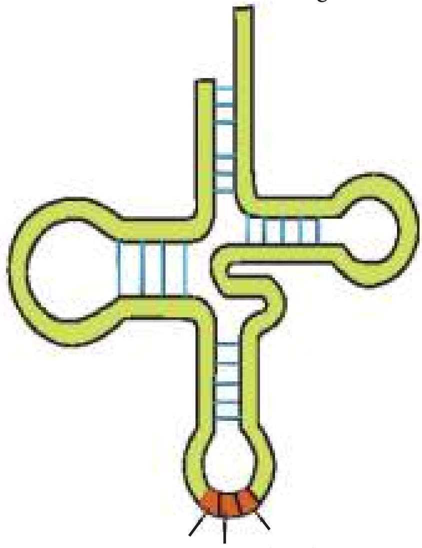


Fig 5.11: Transfer RNA

The RNA ensures that amino acids are arranged correctly corresponding to the coded base sequence in mRNA. Adjacent amino acids are linked by peptide bonds to form polypeptides. The tRNA then peels off and returns to its pool in the cytoplasm where it can be used again.

The table 5.11 below summarises the difference between DNA and RNA.

Table 5.11: Differences between DNA and RNA

DNA	RNA
Has a deoxyribose sugar.	Has a ribose sugar.
Has a double strand (double helix).	Has a single strand.
Found in the nucleus, some in mitochondria and chloroplasts.	Found in nucleus and in cytoplasm.
Has organic bases cytosine, guanine, adenine and thymine.	Has organic bases cytosine, guanine, adenine and uracil.

Sex chromosomes

Every organism has a constant number of chromosomes in its nucleus. In humans for instance, there are 23 pairs of homologous chromosomes. Out of the 23 pairs, 22 pairs determine body characteristics other than those associated with sexual characteristics.

The 22 pairs of chromosomes that determine body characteristics are called **autosomes**. The two chromosomes that form the 23rd pair are called **sex chromosomes**.

They are referred to as sex-chromosomes because they carry genes that determine the sex of an individual.

Genes on the sex chromosomes are described as **sex-linked genes**.

The sex chromosomes may also carry genes whose characteristics are not related to the sex of the individual.

Fig. 5.12 shows a display (Karyotype) of a human male's chromosomes.

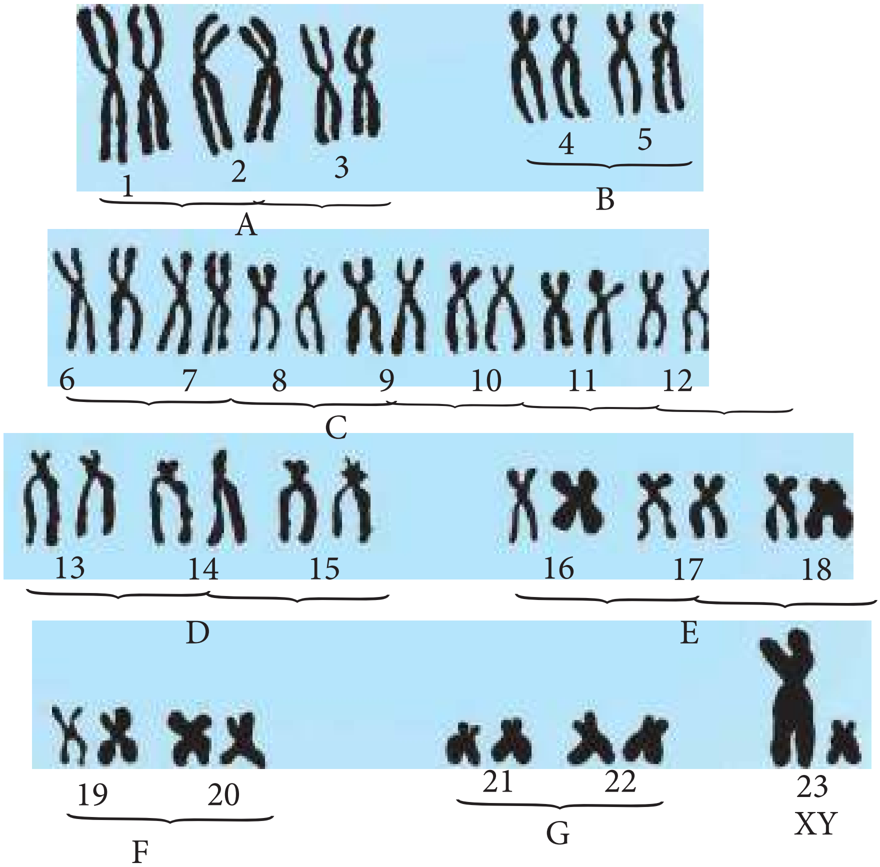


Fig. 5.12: Karyotype of human male chromosomes

The sex chromosomes are shown separately as 'X' and 'Y'. The rest are autosomes.

There are two types of sex chromosomes in humans. One is referred to as the X-chromosome while the other is referred to as the Y-chromosome. The X-chromosome is longer than the Y-chromosome.

Check your progress 5.4

1. What are alleles?
2. State three differences between DNA an RNA.
3. State two structural differences between DNA and RNA.
4. Non-sex chromosomes are called _______.

5.6 Sex determination in human beings

Activity 5.5: Research

1. Using the internet and textbooks, research on the inheritance of sex in humans and sex linkage in haemophilia and colour blindness.
2. Present your findings to the class.

The facts

Every organism has a constant number of chromosomes in its nucleus. In humans for instance, there are 23 pairs of homologous chromosomes. Out of the 23 pairs, 22 pairs determine body characteristics other than those associated with sexual characteristics.

The 22 pairs of chromosomes that determine body characteristics are called **autosomes**. The two chromosomes that form the 23rd pair are called **sex chromosomes**. They are referred to as sex-chromosomes because they carry genes that determine the sex of an individual.

Genes on the sex chromosomes are described as **sex-linked genes**. The sex chromosomes may also carry genes whose characteristics are not related to the sex of the individual. In karyotype of human males chromosomes, the sex chromosomes are separate as **X** and **Y**. The rest are autosomes.

There are two types of sex chromosomes in humans. One is referred to as the X-chromosome while the other is the Y-chromosome.

In humans, these chromosomes can occur in only two combinations. (**Note** that these combinations involve homologous chromosomes, not alleles). These combinations represent the genotypes of the individual. If the genotype is **XX**, the individual develops female characteristics. The sex of the individual is therefore **female.**

If the genotype is **XY,** the individual develops male characteristics. The sex of the individual is, therefore, **male.**

The following example shows a cross between a male and a female.

Parental phenotype	Male		Female
Parental genotype	XY	X	XX

Male / Female	X	Y
X	XX	XY
X	X X	XY

In the cross above, we can also see that the female produces gametes that always have the X-chromosome. The female is therefore said to be **homogametic.**

On the other hand, the male produces gametes that have an X-chromosome and others that have a Y-chromosome. The males are therefore said to be **heterogametic.**

Note: A female passes the X-chromosome to her son while the daughter receives an X-chromosome from the father.

Check your progress 5.5

1. Define linkage in relation to hereditary.
2. A certain man always complains that his wife can only bear female children. Explain to this man using a cross diagram that he is the one responsible for determining the sex of the children.
3. Between a pair of alleles and a pair of chromosomes, what determines the sex of an individual?

5.7 Sex linkage

Study the homologuous pair of chromosome below. What does it show?

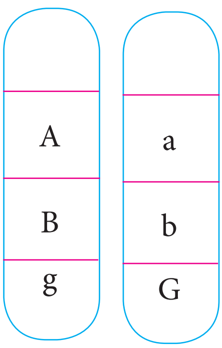


Fig 5.13: A pair of homologous chromosomes

The genes represented by **A**, **B** and **g** are **linked** because they are found on the same chromosome. Genes **a**, **b**, and **G** are also linked because they are found on the other chromosome. The genes found on different chromosomes, that is A and a, or A and G are **not linked** because they are found on different chromosomes.

In humans, some traits are controlled by genes located on the sex chromosomes. Genes carried on the same chromosome are inherited together by the new individual. Since the genes are located on the same chromosome, they are said to be linked. The location of genes on the same chromosome is referred to as **linkage**. The linked genes are always inherited together. The trait is more likely to appear in one sex than the other.

The sex of a given individual is determined by genes found on the sex chromosomes. The sex-chromosomes also carry genes that do not determine the sex of the individual. Since these genes are found on the same chromosome, they are linked and are therefore inherited together. These genes that are found on the sex chromosome are said to be **sex-linked genes.** The characteristics which develop in an individual because of these genes are called **sex-linked characteristics.**

The **Y**-chromosome is shorter compared to the **X**-chromosome. Therefore, the X-chromosomes bear genes that have no corresponding alleles on the Y chromosome. This is because only a small portion of X-chromosome is homologous to the Y-chromosome as shown in Fig 5.14.

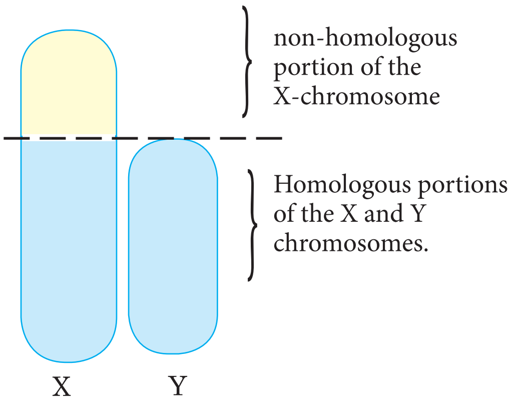


Fig 5.14: Homologous and non homologous portions of the sex chromosomes.

Genes located on the non-homologous part of the chromosome determine certain characteristics which are referred to as **sex-linked characteristics** or traits. Examples of these traits are haemophilia and colour blindness.

Note: The genotype of the individual is written as XX or XY. Since the genes that determine the **sex-linked trait** are located on the unpaired part of the X-chromosome, this linkage is shown in the genotype by a letter representing the gene as a superscript on the X chromosome. If the superscript is capital, it denotes a dominant gene for example **X**H. If it is small letter, it denotes a recessive gene e.g. **X**h.

Haemophilia

Haemophilia, also known as the **bleeder's disease** is a sex-linked trait where the normal allele for blood clotting is replaced by a defective recessive allele. The allele is located on the X chromosome. Therefore, the condition occurs more in males than in females.

The clotting of blood after injury is influenced by many factors including a protein known as blood clotting factor VIII. The inheritance of this factor is determined by two alleles. One allele determines the production of normal clotting factor. This allele is dominant. The other alleles influence formation of a defective clotting factor. This allele is recessive. When the normal clotting factor is present, the blood clots normally after an injury. When the defective clotting factor is present, the blood is slow to clot or does not clot at all. The dominant allele is expressed with a capital H while the recessive allele is expressed by h. These alleles are located on the unpaired part of the X-chromosome.

In females, the possible genotypes are **XH XH**, **XH Xh** and **XhXh**. If the female has genotype **XH XH** or **XH Xh**, the normal clotting factor is produced. Such a person is phenotypically a **normal female.**

If the female has genotype X**h**X**h**, the defective clotting factor is produced and the blood is slow to clot or does not clot at all. Such a person is phenotypically a **haemophiliac female.**

In males, the possible genotypes are XHY and X**h**Y. If the male has genotype XHY, the normal clotting factor is produced. The blood clots normally. Such a person is phenotypically a **normal male.** If the male has a genotype X**h**Y, the defective clotting factor is produced. The blood is slow to clot or does not clot at all. Such a person is phenotypically a **haemophiliac male.**

The relationship between the genotypes in the inheritance of haemophilia is given in the table below.

Table 5.12: Relationship between genotypes and inheritance of haemophilia

Possible genotype	Clotting factor	Phenotype
$X^H X^H$	Normal	Normal female
X^H X^h	Normal	Normal female
X^hX^h	Defective	Haemophilic female
X^H Y	Normal	Normal male
X^h Y	Defective	Haemophilic male

The heterozygous female (XH Xh) is also referred to as a **carrier**. This is because she has a recessive allele for haemophilia which does not show phenotypically.

In a case where a haemophilic male marries a normal female; all girls will be carriers while the boys will be normal.

Male / Female	X^h	Y
X^H	X^HX^h	X^HY
X^H	X^HX^h	X^HY

Note: From the table, it can be noted that the male requires only one recessive allele to be haemophiliac, while the female requires two recessive alleles to be haemophiliac. In a population therefore, the chances of males being haemophiliac is higher than that of females.

Colour blindness

Colour vision is determined by a pair of genes. The gene for normal colour vision is dominant. A normal vision is a situation whereby the individual is able to distinguish all the colours of a given object. The gene for abnormal colour vision is recessive. It brings about a condition known as **red-green colour blindness.** This is the inability of a given individual to distinguish red from green colour.

The alleles for colour vision are sex-linked. They are found on the X-chromosome and are absent on the Y- chromosome. If the mother has the defective allele, there is over 50% chance that the son will receive the defective allele. The daughter, on the other hand, receives an X from the mother and Y from the father. Hence she would only be a carrier.

The dominant allele is expressed with a capital **C** while the allele for abnormal colour vision (colour blindness) is expressed with a small letter **c.**

- In females, the possible genotypes are X**C** X**C**, X**c**X**c** and X**C** X**c**.
- In males, the possible genotypes are X**C**Y and X**c**Y.

The relationship between the genotypes in the inheritance of colour blindness is given in the table below.

Table 5.13: Relationship between genotype and inheritance of colour blindness

Genotype	Phenotype
XC XC	Normal female
XC Xc	Normal female
XcXc	Colour blind female
XC Y	Normal male
Xc Y	Colour blind male

If a man with normal colour vision marries a colour blind woman and they have children, then the possible genotypes would be:

Male / Female	X^C	Y
X^c	$X^C X^c$	X^cY
X^c	X^CX^c	X^cY

From this cross, all boys will be colour blind but half of the girls will be colour blind while the other half carriers.

Check your progress 5.6

1. What is haemophilia?
2. On which chromosomes is the gene that cause haemophilia linked to?
3. Sex-linked gene ____________.
   a) are located on the X-chromosome
   b) control the production of sex chromosomes
   c) are located on sex chromosomes
   d) are expressed more in females
4. What is the probability that the sons of a colour blind man and a normal homozygous woman will be colour blind?
5. A haemophiliac man has two sons, one normal and the other haemophiliac. What is the probability of the couple getting a haemophiliac daughter?
6. State the possible genotypes of a normal person in relation to haemophilia.

5.8 Variations among organisms

Look at the tree diagram below. What is it about?

Assuming children **C** and **E** are daughter and son respectively of parents **A** and **B**, where do you think the difference in the colour of hairs came from? Why did the bald head of parent **A** disappear?

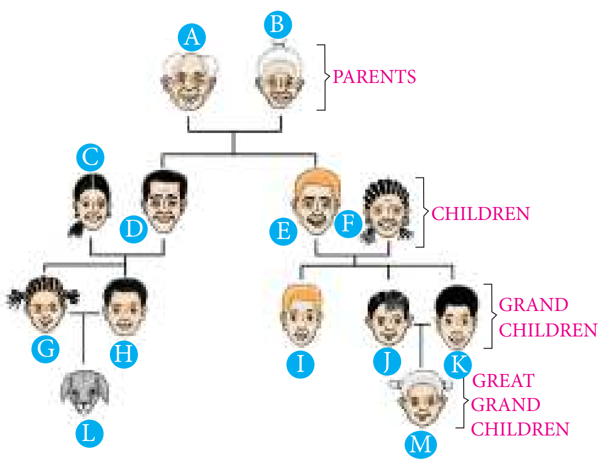


Fig 5.15: Family tree

From which parent is grandchild I likely to have obtained the characteristics of her hair; E or F? Why? Why would you say great grandchild L is far from reality? Based on your analysis of the chart, what do you think this genetics is about?

You may have realised that though organisms may be from same parents, they show differences in their characteristics. This is an example of **variation**.

In this topic, you will learn about variation and how the variations adapt the organisms to their habitats.

Activity 5.6

Work in groups.

1. You are provided with charts and pictures of plants and animals of the same type.
2. Observe the pictures carefully. Note down the characteristics of the animals in the pictures.
3. Look at your classmates.
   - What variation can you see in the shade of skin, hair colour or texture, height and build?

The facts

Your friends and classmates may have different eye colour and skin colour. Some will be boys and some will be girls. Some will be tall and some will be shorter.

The word 'variation' comes from the word 'vary' which means 'to differ'. **Variation** therefore refers to the differences within the observable and non observable characteristics in a given species of organisms. Variation is used to place each organism in its own taxonomic group. For instance, given a goat and a domestic fowl, we use differences such as presence of mammary glands, skin covered with fur or skin covered with feathers to place the goat in class – Mammalia and the domestic fowl in class – Aves.

A gene is usually said to be epistatic if its presence suppresses the effect of another gene at another locus. Epistatic genes are sometimes referred to as inhibiting genes due to their effect on another gene. For example, fur colour in mice is usually controlled by a pair of genes which occupy a different loci. The epistatic gene mostly determines the presence of colour in an organism and usually has two alleles i.e. albino (white which is recessive) and coloured (which is usually dominant). Therefore, mice with black fur will only appear black if it's accompanied with an allele for coloured fur. The albino mice arises as a result of its homozygous recessive for colour being present even if the allele for black fur is present. This phenomenon can be used to account for variation in colour among different animals which have different colours such as goats and domestic fowl.

Variation between different species is usually greater than the variation within a species. For instance, in dog species, all have skin covered with fur. But the fur coat has different colours. The colours may be black, white or brown. These differences in the colour of the fur constitute variation within the characteristic of fur colour.

Variation among organisms of the same species can be caused by one or some of the following factors.

- Separation of chromosomes during gamete formation and crossing over during meiosis.
- Mutation, which is the sudden change in the structure and amount of genetic material in the cells of an organism. They can be caused by mutagens such as UV rays, cosmic rays and other chemicals.
- Sexual reproduction, where a zygote is formed by gametes of two parents with varied features.
- Environmental characteristics determine how an organism will grow and how characteristics in it will be developed.
- Characteristics are known to develop with age. Differences in age results to differences in the development of characteristics such as weight and height in offspring produced from the same parent.
- Heredity is the passing on of physical or mental characteristics genetically from one generation to another.

There are two main types of variation, namely genetic variation and phenotypic variation.

Genetic variation

You probably look similar to your parents and siblings and they look similar to their parents and siblings. However, you do not look exactly the same and this is due to **genetic variation** that causes differences in external characteristics.

You get your genes from your parents, that is why you and your siblings look similar to them and each other. Your genes have *alleles* which are different forms of the same gene. Alleles are like a code for your body that determines hair colour and eye colour, height and other genetic features.

Genetic variation refers to differences amongst organisms of the same species caused by the differences in the genes they inherit from their parents. Some individuals are tall and others are short. This is because they inherited different genes from their parents. Such variations can be inherited because they are genetically determined.

Note: Genetic variation is the variation in alleles and genes, both within and among populations.

Phenotypic variation

Phenotypes are traits or characteristics of an organism that we can observe, such as size, colour, shape, capabilities, and behaviours. Not all phenotypes can actually be seen. For example, blood types are phenotypes that we can only observe using laboratory techniques. Phenotypes can be caused by genes, environmental factors, or a combination of both.

Phenotypic variation is the variability in phenotypes that exists in a population. This type of variation can be due to inheritance of genes and also to environmental factors such as climate and diet. The external environments that can bring about phenotypic variation include:

- climate
- diet
- physical accidents
- culture
- lifestyle

Organisms of the same species may be exposed to different environmental factors such as temperatures, light, humidity and nutrients. Man-made factors such as loss of body parts through accidents, dehorning of cattle and lightening of the skin using cosmetics contribute to the variation. Such variations are not genetically acquired but environmentally acquired. These characteristics cannot be passed from parents to their offspring.

Many kinds of variation are influenced by both environmental and genetic factors. Although our genes decide what characteristics we inherit, our environment affects how these inherited characteristics develop. For example:

- A person might inherit a tendency to be tall, but a poor diet during childhood will cause poor growth.
- Plants may have the potential for strong growth, but if they do not receive sufficient mineral resources from the soil, they may hardly grow at all.
- Identical twins are a good example of the interaction between inheritance and environment; as such twins are genetically the same. Any differences you may see between them, for example in personality, tastes and particular aptitudes are due to differences in their experience or environment.

Table 5.14 Comparison between genetic variation and phenotypic variation

Genetic variation	Phenotypic variation
Are due to genes.	Are due to environmental factors e.g. food, climate and diseases.
Re-appear in offsprings	Cannot reappear in offsprings.
Mainly unchangeable	Sometimes changeable in lifetime e.g. one may lose weight.

Check your progress 5.7

1. Joan has bright blue hair. What kind of variation has caused this?
   A. Inherited
   B. Environmental
   C. Intended
   D. Dyed
2. What does the term variation mean?
   A. Differences in an organism.
   B. Difference in the population.
   C. Difference within a characteristic.
   D. Difference in body structure.
3. State the differences between genetic variation and phenotypic variation.
4. Identify some of the sources of environmental variation.

5.9 Continuous and discontinuous variation

Continuous and discontinuous variations are influenced by genes, hence a type of genetic variation.

Continuous variation

Some variations in individuals in a given species show many slight differences in a given characteristic. The differences range from one extreme end to another with many intermediate forms in between.

Activity 5.7: To measure and record height of class members

Work in groups.

Requirements

- Metre rule
- Notebook

Procedure

1. Ask each member of your group to stand straight against a vertical wall.
2. Measure the height of each member from the heel to the top of the head using the metre rule.

Fig. 5.16: Measuring height

3. Record the height of each member in your notebook.
4. Get the heights recorded by other students in other groups and record in your notebook.

Study questions

1. From the data in your notebook, identify:
   (a) The shortest height.
   (b) The tallest height.
2. Can you group the students into two groups (tall or short)?
3. If your answer in (2) is no, try to put the heights obtained into various groups or classes according to their range; for instance, the number of students with a height of between 100 cm – 109 cm. Count the number of students in each range.

   This number is known as the frequency (number of students who are found in a given range of height). Fill the table below.

Range	Frequency
100-109	
110-119	
120-129	
130-139	
140-149	
150-159	
160-169	

4. Draw a histogram or a graph from the data above.
5. Determine the mean, median and mode.
6. Identify the range with the least number of students.
7. Identify the range with the largest number of students.

The facts

Measurement of heights of class members differed slightly from one extreme end to the other. In each case, there was a measurement to the lower extreme end and a measurement to the higher extreme end. In between the two extremes, there were intermediate measurements that differed slightly from each other. In this case, the variations in the measurements could not put the individuals studied into distinct groups. The variations demonstrate continuous variation.

Continuous variations are controlled and influenced by the environment, for example, you may have genes that can influence you to grow tall. However, if you do not eat enough food, you may become malnourished and have stunted growth. Some examples of characteristics that show continuous variation are listed below:

- Height
- Weight
- Stem diameter in plants
- Length of leaves
- Length of internodes in plant stems
- Skin colour in humans
- Size of seeds and fruits
- Length of fingers in humans

This is the type of variation of a given character or trait where differences among organisms of the same species are slight and grade into each other. These characters can be measured and the mean, mode and median can be obtained.

This is a type of variation where there is a range of values; a line graph is always used to express continuous variation. If you plot frequency as a histogram or as a frequency polygon, you will find that most of the values are close to the average (mean), and extreme values are actually rather rare.

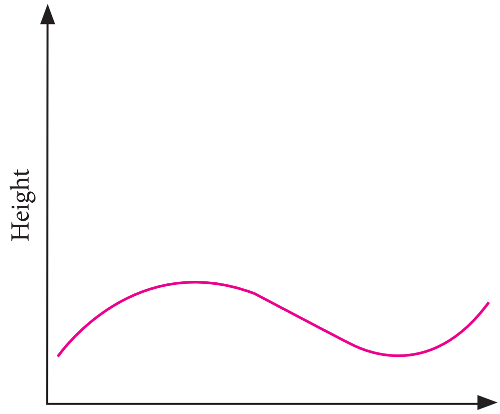


Fig 5.17: Plot of range in height against frequency

Discontinuous variation

Some characteristics in a given species show definite or distinct differences; there are no intermediates.

Activity 5.8: To investigate discontinuous variation

Work in groups

Materials

- Pipette
- Swab
- Antiserum
- Alcohol
- Slides
- Pricking needle

Procedure

1. You are provided with the above materials. Come up with a procedure to test blood type.
2. Act as a subject and test your blood group.
3. Collect results of each person in your group and draw a graph based on the results collected.
4. Also in your groups, let each person try rolling their tongue.
   - How many people are able to roll their tongue?
   - How many people are able to roll it half way?

- How many people are not able to roll their tongue?

5. In your respective groups, divide yourself into groups of male and female.
6. Count the numbers and fill your results in a table like the one shown below.

Male	
Female	
Total	

7. Plot a histogram showing those who are males and those who are females.

Study questions

(i) How many students are male?
(ii) How many students are female?
(iii) Why do you think these are examples of discontinuous variation?
(iv) Suggest other characteristics in your class members that can put them into distinct groups.

The facts

Students were either male or female. The characteristic for sex therefore has two variations that are distinct from each other. This type of variation which shows clear-cut and sharp differences amongst organisms over a given trait is **discontinuous** variation.

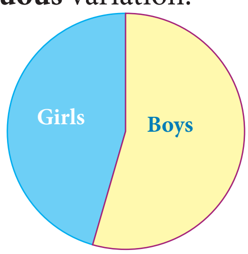


Fig 5.18: Pie-chart on distribution of students in a school by sex

In discontinuous variation differences do not merge into each other and therefore there are no intermediate grades. The features cannot be measured but can be observed. A normal distribution curve cannot be obtained. For example in a class of 49 students, it was found that 10 students were able to roll their tongues, while the rest were not capable. The information above can be represented in a bar graph as shown in Fig. 5.19.

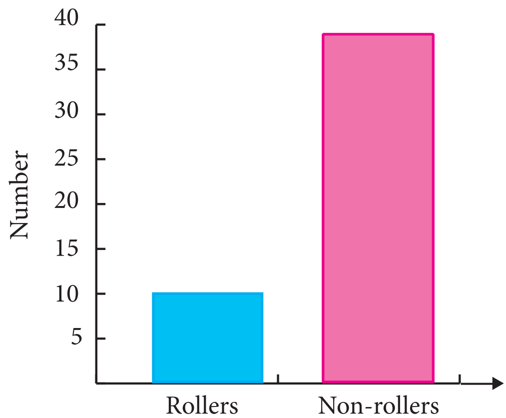


Fig 5.18: Graph of rollers and non-rollers

The features persist throughout the life time of an organism. They show distinct differences. The table below summarises examples of discontinuous variation.

Table 5.15: Examples of discontinuous variation

Characteristic trait	Variation
Leaf venation	Parallel or network
Sex	Male or female
Rhesus factor	Positive or negative
Blood groups	A, B, AB or O

Characteristic trait	Variation
Finger print patterns	Tentrach, mixed or double looped, or pocked
Skin coat in dogs	Rough or smooth
Flower colour in garden pea	Red or pink

Did you know?

All these characteristics are not affected by environmental condition.

Some characteristics like blood groups and finger print patterns have more than two variations.

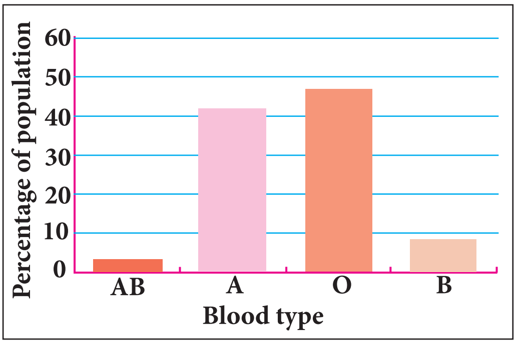


Fig 5.19: Blood groups

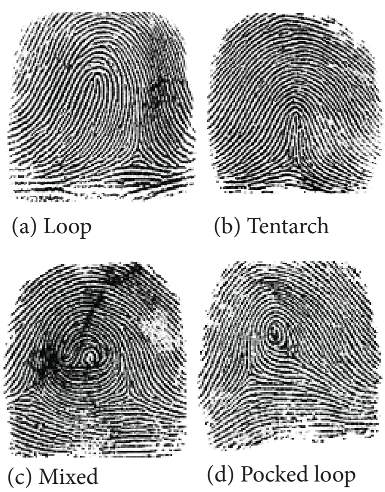


Fig. 5.20: Finger-print patterns

Activity 5.9: Investigating the difference between continuous and discontinuous variation

Work in groups

1. Discuss the difference between continuous and discontinuous variation.
   - Note the differences in the table shown below.

Continuous variation	Discontinuous variation

2. Present your findings to the rest of the class.

   Did your table look like this?

Table 5.16: Summary of the differences between continuous and discontinuous variation

Continuous variation	Discontinuous variation
Show no clear-cut distinction.	Show clear-cut distinction.
Show intermediate between two extremes.	No intermediate form.
Character influenced by environment.	Character not influenced by environment.

Check your progress 5.8

1. Group the following characteristics as either continuous or discontinuous variation.

   Gender, blood group, weight, height, length of forearm,

2. Which of these factors can be changed by both environmental and inherited variation?

   A. Tattoos B. Scars

   C. Weight D. Dye

3. Where is most variation found?

   A. Between different species

   B. Within one species

   C. Lions and tigers

   D. Among human beings

4. Using a table, give the difference between continuous variation and discontinuous variation.

5.10 Mutations

Activity 5.10: Discussion

Work in pairs.

1. You want to send a text message to a friend using your mobile phone and this is what happens.

   (a) Original message:
   HE CAME WITH HIS THERM**O**

   Conveyed message:
   HE CAME WITH HIS **MO**THER

   (b) Original message:
   HE IS EATING

   Conveyed message:
   HE IS **HE**ATING

   (c) Original message: THE COW SHADE IS DIRTY

   Conveyed message: THE CO**B** SHADE IS DIRTY

2. What do you think will happen to your intended message and the recipient?

3. What do you suppose will happen to a gene sequence in a chromosome if the above takes place in DNA structure?

The facts

If one thinks of the information in DNA as a series of sentences, mutations are therefore errors in spelling the words that make up those sentences. Sometimes mutations are inconsequential, like a misspelled word whose meaning is still quite clear. At other times mutations have stronger consequences, like a sentence whose meaning is completely changed.

Mutations are alterations to a DNA sequence resulting into the formation of new alleles. These new alleles also bring about new characteristics in a population. Mutations can also function as tools of evolution, aiding in the development of new traits, characteristics or species. There are two types of mutations:

1. Gene mutation which occurs as a result of altering the chemical structure of genes. There is a change in sequence of nucleotides in the segments of DNA corresponding

to one gene. This in turn alters the sequence of amino acids required in the synthesis of a particular protein. The protein formed will be different from the normal one and will produce profound effects on both the structure and the development of the organism. Gene mutation is associated with certain genetic disorders such as albinism, haemophilia, colour blindness and dwarfism.

Table 5.17: Gene mutations

		Explanation
Unmutated DNA Base triplets on RNA Amino acids	A-T-A-G-C-T-C-G-C U-A-U-C-G-A-G-C-G Tyr Arg Ala	
Substitution Mutated DNA Base triplets on RNA Amino acid	A-C-A-G-C-T-C-G-C A-G-U-C-G-A-G-C-G Cys Arg Ala	The base thymine on the first DNA triplet has been replaced by cytosine.
Insertion Mutated DNA Base triplets on RNA Amino acids	A-T-A-C-G-C-T-C-G-C U-A-U-G-C-G-A-G-C-G Tyr Ala Ala	An extra base cytosine has been inserted between the original first and second DNA triplets.
Deletion Mutated DNA Base triplets on RNA Amino acids	A-T-A-C-C-T-C-G-C U-A-U-G-G-A-G-C-G Tyr Gly Ala	The base guanine on the second DNA triplet has been deleted.

2. Chromosomal mutations which involve changes in structure of a chromosome or a change in the number of chromosomes in a given individual. This may lead to failure of development of some body parts or over emphasis of a particular trait.

Mutations can be caused by:

a) The DNA failing to copy accurately. Such mutations lead to evolution because they are naturally-occurring. For example, when a cell divides, it makes a copy of its DNA. Sometimes the copy is not quite perfect. This small difference from the original DNA sequence is a mutation.

b) External influences such as exposure to specific chemicals or radiation. These agents cause the DNA to break down. These agents are known as mutagens.

Health check!

Ionising radiations from particles, X-rays or gamma rays or chemicals in nuclear plants increases the rate of mutation.

The whole human family is one species with the same genes. Mutation creates slightly different versions of the same genes, called alleles. These small differences in DNA sequence make every individual unique. They account for the variation seen in human hair colour, skin colour, height, shape, behaviour and susceptibility to disease. Individuals in other species vary too, in both physical appearance and behaviour.

Genetic variation is useful because it helps populations change over time. Variations that help an organism survive and reproduce are passed on to the next generation. Variations that hinder survival and reproduction are eliminated from the population. This process of natural selection can lead to significant changes in the appearance, behaviour or physiology of individuals in a population in just a few generations.

Once new alleles arise, meiosis and sexual reproduction combine different alleles in new ways to increase genetic variation.

Check your progress 5.9

1. Which of the following would be responsible for an increased rate of mutation?
   A. Ultra sound
   B. Ultra violet light
   C. Infra-red light
   D. All of the above.
2. What is the most likely cause of the unexpected appearance of a new characteristic within a species?
   A. Mutation
   B. Crossing over
   C. Reproduction
   D. Evolution
3. Mutation always causes a mutant phenotype. True or false.

5.11 Evolution

Look at the figure of how human beings evolved below. Can you list down the very contrasting characteristics between figure **A** and **E**? How about figures B to E, can you note some differences? Write them down.

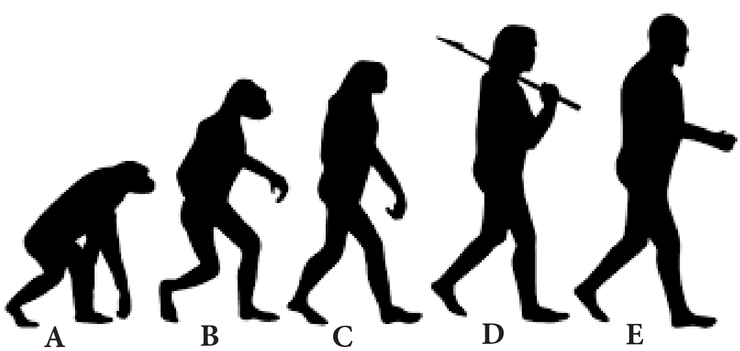


Fig 5.21: Evolution in human being

What do you think necessitated the change in characteristics between the early human being (Figure A) and modern day human being (Figure E)? How is this significant? Based on this, how do you think human beings will look like 1 million years from now considering the fact that we are living in the computer age?

Introduction

When you look around your environment, you realise that plants and animals, live or die according to their ability to survive in that environment. For example, plants are always competing with others for light and water. Animals on the other hand compete for food, space, mates and shelter. In the process, some of these organisms survive, while others die.

This process is known as **selection** process. When it happens naturally, it is **natural selection**. Sometimes human beings influence such a selection process by manipulating the environment. This is known as **artificial selection**.

Fig 5.22: Climber plants and tall trees in a forest

The facts

The term **evolution** is derived from the word 'evolve' which means 'gradual change over a long period of time' Evolution is a theory. The evolution theory tries to explain how the great diversity of animals and plants that exist on earth today has come to be. It suggests that life on earth began from simple forms which then slowly evolved into the present day organisms.

This was because the original simple forms of organisms underwent small changes that accumulated over millions of years, thus selection. This led to the great variations of the complex plants and animals we have today. Therefore, selection is evolution's engine. Selection acting on random variation makes adaptive evolution possible.

Theories of organic evolution

There are many theories that have been put forward that attempt to explain how new life forms emerged (arose) from pre-existing ones. The following are some of the possible mechanisms of evolution, namely Lamarck's theory and Darwin's theory.

Activity 5.11: Observing natural and artificial selection

Work in groups.

You will be provided with documentaries, CDs, pictures and computer simulations.

1. Observe the materials provided carefully.
   - Relate extinct animals and present species to determine course of evolution.

- Differentiate between Lamarck's theory of evolution and Darwin's theory of evolution.

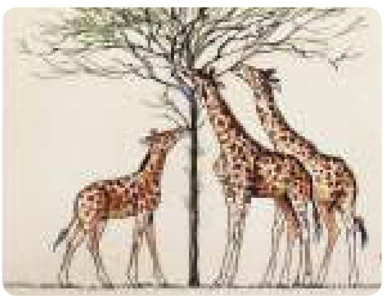
2. Present your findings to the rest of the class.

Lamarck's theory of evolution

The French naturalist Jean-Baptiste de Lamarck proposed that an organism developed a particular structure in response to demand of the environment. This led to the principle of '***Natural use and disuse of structure***'. He observed that the more an individual used a part of its body, the more developed that part became.

Conversely, if an individual failed to use a particular part of its body, that part weakened and finally became rudimentary. This explains the presence of vestigial structures.

He cited an example of the development of the long neck of giraffes. He proposed that the long neck was as a result of stretching upwards by some short-necked giraffes towards the higher levels of vegetation in competition with other browsers for food (Fig 5.24). The long-neck trait was then passed to the next generation, giving rise to a new long-necked species, the present-day giraffes.



a) Original giraffes with variations in neck length

b) Short necked giraffes die during competition while long necked giraffes survive

c) Long necked giraffes emerge

Fig 5.23: Natural selection in giraffes

He cited another example of the flightless birds such as ostrich, kiwi and emu. He proposed that such birds lived in an environment not requiring flight, hence their wings reduced and become functionless. Lamarck concluded that the giraffe developed the long neck due to its use, while the flightless birds had their wings reduced and functionless due to the disuse.

Lamarck proposed that these changes or structures acquired during the lifetime of an individual were then transmitted (passed) to their offsprings and subsequent generation, resulting to emergence of new species.

Merits of Lamarck's theory

According to Lamarck an individual is able to develop structures to suit the need of the environment.

This enables the organisms to survive in diverse environments. His theory shows the importance of exercise and training, for example, in the development of muscles of a weight lifter. Advantageous traits are perpetuated in a species from one generation to another while less advantageous traits are eliminated.

Demerits of Lamarck's theory

Modern genetics show that phenotypically acquired characteristics, which do not affect the genotype of an individual, cannot be inherited. Lamarck had proposed that acquired characteristics in a lifetime are inherited.

Darwin's theory of evolution

Charles Darwin proposed that in nature there exist a phenomenon called '***Natural selection***'. He observed the occurrence of variations within a species, which arose by chance and from an individual. Such variations (changes) were then passed to the offsprings and subsequent generations.

The accumulation of small variations over a long period of time led to the emergence of new species. Darwin observed that the number of offsprings were always bigger than those of the parents, but only a few of the offsprings survive to adulthood and are able to reproduce for the next generation. He pointed out that in any given environment there exists limiting factors (eliminating factors) such as competition for food, space, diseases, predation among others.

Therefore, in life, there is always a '***struggle for existence***' and only those best suited for that environment survive while the least suited are eliminated. He called this principle '***the survival for the fittest***'. The main points in Darwin's theory of evolution are as follows:

(a) Living organisms tend to produce more offsprings than the environment can support.

(b) There is always competition or struggle for existence between the organisms for the limited resources such as food and space.

(c) Only the fittest organisms survive while the less adapted are eliminated.

(d) Natural selection is by chance. Neither the environment nor the individual itself control the direction of the change.

Charles Darwin studied this phenomenon of natural selection which later came to be called *Darwin's theory of natural selection*. Darwin worked together with *Alfred Wallace* to formulate this theory. The idea was that *members of a species compete with each other for resources and that individuals that are better adapted to their lifestyle have a better chance of surviving to reproduce.*

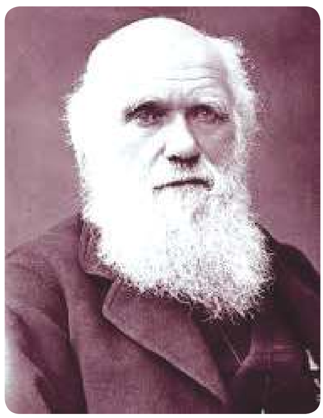


Fig 5.24: A portrait of Charles Darwin

Natural selection causes evolution

because with time and over many generations, favourable adaptations gradually accumulate in the species, while the unfavourable ones disappear. This leads to a change or evolution in the species.

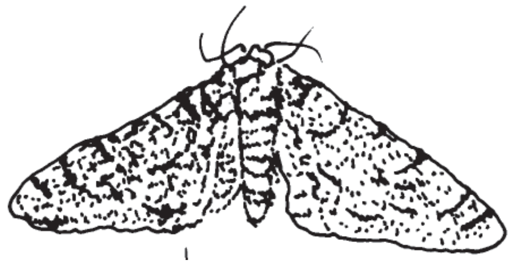
Sometimes, the accumulated changes become so many that the eventual outcome may be a species that cannot reproduce and have viable offspring with the original one. This means that the gradual changes have led to the formation of a new species. This is called **speciation.**

Evolution occurs slowly and continuously over millions of years by natural selection. Other sources of variations that contribute to natural selection in a species include:

- Mutations
- Recombination of genes as a result of sexual reproduction.
- Migration of individuals between populations which lead to introduction of new genes in the population.

An example of natural selection is exhibited by:

I. The **peppered moth**, ***(Biston betularia)***. This is a moth commonly found in England. There are two types of such moths which vary in body colour. These variations in colour are: **light** body colour and **dark** body colour. The variations are genetically determined. The dark body colour in the moth is due to a pigment called **melanin** whose occurrence is caused by a mutation. The moth with this body colour is called the **melanic form.** This type was very rare in England before industrialisation. After industrialisation, it was observed that the number of the melanic forms increased around the areas with industries.



(a) Light coloured moth

(b) Dark coloured moth (melanic form)

Fig 5.25: Different forms of Peperred moth

II. Resistance to drugs, pesticides and antibiotics by disease causing micro-organisms.

Merits of Darwin's theory

According to Darwin, the natural selection ensures that only the best suited individuals develop to maturity and reproduce for the next generation. As a result, the numbers of a species tend to remain relatively constant due to the regulating factors such as food, disease and predation.

Demerits of Darwin's theory

Darwin's theory did not explain how changes occurred by chance. Modern genetics however explain those changes that Darwin proposed as gene or chromosomal mutations, which occur randomly and suddenly.

Darwin was also not able to explain how transmission of traits occurs. Modern genetics shows that there are factors called genes that are found in the chromosomes within the nucleus which carry genetic information.

Role of mutations, natural selection and adaptive changes in evolutionary changes

Mutations bring about changes in characteristics in a group of organisms in a species. The new characteristics may be favourable in the environment where an organism is found. This results in the mutant characteristics surviving and reproducing offspring with the same characteristics. Such characteristics may accumulate in a given species over a period of time. This contributes to evolutionary changes.

In the same way, organisms with favourable characteristics survive due to natural selection, while those with unfavourable features are slowly eliminated. Over a period of time, the organisms with favourable characteristics inhabit a given area, showing differences with organisms that used to live there years back. This demonstrates evolutionary changes in a given species. For example, in a given arid ecosystem, there may exist cactus of different variations, some with long roots, while others have short roots. Both types of cactus reproduce highly during the wet seasons. During dry seasons, the cactus with long roots are able to obtain water from deep in the soil. They reproduce and increase in population. The cactus with short roots cannot reach down for water. They have a slow rate of population increase. Over many years the area will be inhabited by cactus with long roots only. The ones with short roots are eliminated.

Check your progress 5.10

1. Through careful observation, Charles Darwin came to understand that:
   A. Populations of plants and animals in nature most often consist of individuals that are clones of each other.
   B. Those individuals whose variation gives them an advantage in staying alive long enough to reproduce are more likely to pass their traits on to the next generation.
   C. Populations of a species that become isolated from others by adapting to different environmental niches quickly become extinct.
   D. All of the above.
2. What is polymorphism?
3. State the limitations of Lamarkism and Darwinism.

5.12 Genetic engineering

Read this story then answer the study questions.

Kenyi and his wife Alarn are now in their sixties. They have lived in a maize growing village in Malek district for the entire period of their lives. In the past, they used to sustain their families by growing local maize in the farm.

In those days, rainfall was reliable and they were sure to get enough harvest to last them for a whole year. However, in the last three years, the varieties of local maize they used to plant have been disappointing them. He found himself going to the shops to buy maize since his granaries were empty. He could not understand why the crop that had all along sustained his family was now producing only 2 bags per hectare, a harvest that is hardly enough to sustain him and his seven children and 10 grandchildren.

Fig 5.26: Harvesting maize

His story remained a mystery, until last year when agricultural officers visited his home and introduced to him a new variety of maize that had recently been produced at ***Karama Research Station****. Throughout his life, Kenyi thought that all maize were the same. At first he thought that the officers were not genuine in their mission. He reluctantly accepted to plant the new variety popularly known as ISAR MO81. To save his old tradition, he decided to plant one hectare of local maize and one hectare of the new maize variety that he called 'maize from Karama'.*

To his amazement, the new variety matured far much earlier than his local maize. It produced large kernel and most of the stems produced two cobs. He ended up harvesting 40 bags of the ISAR MO81, while the local variety could hardly reach maturity before the rains stopped. He only managed to get 2 bags of harvest from them. Kenyi had also discovered something else; the new variety according to him produced better flour that made his children like the 'ugali' prepared from it.

Fig 5.27: New maize growing in a large kennel.

From that day onwards, Kenyi has vowed never to go back to the local variety of maize. He now has enough maize to feed his large family and surplus to sell.

Study questions

1. What two observations can you make about Kenyi's farming?
2. What type of work is done in research stations?
3. Identify three good qualities of *ISAR MO81* over local varieties of maize.

Gene technology is used to produce new breeds of animals with better production output and new varieties of crops with higher output and which are more resistant to drought and diseases. It is a part of a wider branch of Biology known as **biotechnology**.

Biotechnology refers to productive application of Biology in research and industry to maximise output. Biotechnology is involved in cultivation of food plants that produce high-yielding crops, production of antibiotics, enzymes and hundreds of other products.

In biotechnology, the organisms are not always modified to be different, but their natural processes are enhanced to get the optimum product.

Fig 5.28: GMO maize plantation

The main streams that biotechnology touches are cell and tissue culture, genetic engineering, microbiology, embryology and molecular biology. In this unit you are going to learn about **genetic engineering**.

Activity 5.12: Field study

Work as a class

1. With the assistance of your teacher, organise a visit to a crop field and an animal farm.
2. During the visit, study the following:
   - Type of crops and animals found.
   - How technology is applied in the farm.
   - The impact such farms make to the community and the country as a whole.
3. Write a report of the study.

Application of genetic engineering in biotechnology

Activity 5.13: Research Activity

Work as a class.

1. Using textbooks and the internet, research on the need for genetically modified crops.
   - Why are they important?
   - How does that improve world's food supply?
2. Suggest plants that require less fertilizer, resist drought, diseases, pests and cold weather to produce more nutritious or abundant fruit.
   - How do you suppose these plants are produced?
3. Write a report of your findings.
4. Present your findings to the rest of the class.

The facts

Genetic engineering is a biotechnological application where useful DNA or genes of organisms are manipulated according to the requirement. Genetic engineering is used mainly to benefit the needs of human beings. In genetic engineering, an identified gene of an organism that is responsible for a certain function is isolated and introduced into another organism. The introduction of foreign genes into an organism's gene makeup (genome) is performed through the techniques of Recombinant DNA Technology (RDT).

Fact of life: The first use of RDT was demonstrated in 1972.

The organism to which the gene has been introduced is called the **genetically modified organism** (GMO). When a certain food is produced through a genetically modified organism, it will be a genetically modified food. Production of food and medicine has been the main practice performed through genetic engineering. In addition, the use of genetic engineering has started to benefit the agricultural crops so that there is increased immunity against insects or herbicides.

Genetic engineering is different from traditional cross breeding, where genes can only be exchanged between closely related species. With genetic engineering, genes from completely different species can be inserted into one another.

Genetically modified organisms do not have a great chance of surviving in nature. They need special conditions or management of their population sizes. This is because natural selection did not take place and may be disastrous for the genetically modified organisms.

Cloning

Cloning is the production of many genetically identical species of an individual through asexual reproduction. Cloning of sheep, Dolly, in 1997 was one of the steps made in terms of genetics and biotechnology.

This technology raised the possibility of breeding many identical copies of animals including the transgenic animals which possessed desirable features.

In this process, a donor cell is taken from the sheep's udder and fused with the nucleus of an egg cell obtained from an adult female sheep using an electric shock. The fused cell starts dividing normally, resulting in formation of an embryo which is placed in the uterus of a foster mother sheep. This embryo then develops normally into a lamb called a dolly.

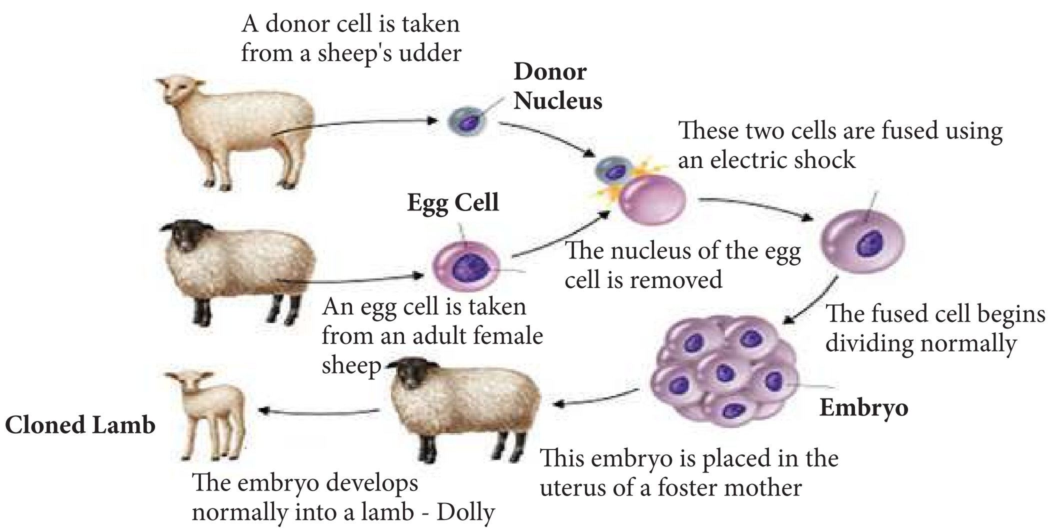


Fig. 5.29: Cloned dolly sheep

Advantages of cloning

1. The produced organisms are genetically identical and they possess desired characteristics.
2. Organisms that are difficult or slow to breed can be reproduced quickly.

Disadvantages of cloning

1. If a clone is susceptible to disease or changes in environment, then all the clones will be susceptible.
2. It will leads to less variation and less opportunity to create new varieties in the future

Genetic engineering in vitamin production

Vitamins are essential as nutritional components and are indispensable for the maintenance of many metabolic processes. They cannot be synthesised in the human body and have to be taken up in sufficient amounts from food. An insufficient vitamin supply can lead to deficiency diseases.

There are various methods for production of vitamins: chemical synthesis, biotechnological methods with the help of microorganisms, extraction from plants or herbal material.

For some vitamins, production methods have now been developed that use genetically modified microorganisms:

- Vitamin E can be produced both biotechnologically or from soya beans. For extractions from soya beans, it is probable that a certain percentage is derived from genetically modified plants.
- Many vitamins, especially the fat-soluble vitamins A, D, E and K, are attached to carrier molecules for better handling. Gene technological methods can be utilised for producing some of these carriers, e.g. starch, glucose and maltodextrin.

Genetic engineering in pest resistance crops

Genes can also be inserted or removed from crop plants to improve their characteristics or traits. Such plants that are as a result of genetic engineering are called **transgenic plants**. Genes for insect resistance now can be moved into plants more quickly and deliberately. *Bacillus thuringiensis,* commonly known as Bt, is a bacterium that occurs naturally in the soil. Some strains of Bt produce proteins that kill certain insects with alkaline digestive tracts. When these insects ingest the protein produced by Bt, the function of their digestive systems is disrupted, producing slow growth and ultimately death.

Bt is very selective, that is different strains of the bacterium kill different insects and only those insects. Strains of Bt are effective against corn borers, cotton bollworms, certain flies and mosquitoes. Bt is not harmful to humans, other mammals, birds, fish or beneficial insects. The table below shows examples of traits that can be genetically modified and the plants they can be done with.

Table 5.18: Other examples of genetic engineering

Example	Gene donor	Gene receiver	Benefit
Golden rice	Carotene gene from carrots	Rice	People lacking vitamin A in their traditional diet can make the vitamin if they eat genetically modified 'golden' rice.

Example	Gene donor	Gene receiver	Benefit
Insect resistance	Resistant gene from bacteria	Maize and cotton	Confer resistance to insect pests.
Weed killer resistance	Resistant gene from plant	Soya beans	Genetically modified soya beans can be sprayed with weedkiller and remain unaffected, so only weeds are killed. This increases yields of soya.

Genetic engineering and herbicide resistance

Herbicide tolerance is a plant's ability to endure the effects of a herbicide at the rate normally used in agricultural production. Herbicide resistance is the ability of a plant to be unaffected at any feasible rate of herbicide application. Most crops are resistant to one or more herbicides. Genetic engineering has provided plant scientists with additional tools to determine the chemical and genetic modes of action of many of these herbicides and also the mechanisms that account for a plant's natural tolerance or resistance to herbicides.

Scientists use this knowledge to incorporate herbicide tolerance into crop plant species. This is done by:

- Finding a closely related species that has herbicide tolerance or resistance and then incorporate that tolerance into the desired plant.
- Use of cell or tissue culture to test many different lines of plants for tolerance to a specific herbicide.
- Determining the specific gene or genes within a plant or microbe that allow tolerance or resistance to a specific herbicide.

Genetic engineering in industrial manufacture of insulin

Activity 5.14: Observing the process of insulin production

Work in groups.

1. You will be provided with diagrams, charts, micrographs or simulations on insulin production.
2. Observe the process of insulin production.
3. List the steps involved in production of insulin.

The facts

The human body is capable of producing insulin from the pancreas. The pancreas however might not function properly because of disease and age. The body therefore will face a shortage of insulin which results into an increase in blood sugar level. When this increase is not checked, it will develop into a condition known as *diabetes mellitus*. Scientists through history have always tried to find methods of obtaining insulin.

For many years, insulin was obtained by purifying it from the pancreas of cows and pigs slaughtered for food. The insulin obtained was introduced to the patient in form of an injection. This proved to be expensive and difficult. Although cow and pig insulin are similar to human insulin, their composition is slightly different. In 1955, the structure of human insulin was found, and insulin from cows and pigs were chemically modified to be the same as human insulin.

The insulin produced could cause allergic reactions to the recipient and also lead to long term complications ensuing from the regular injection of a foreign substance. Projected decline in the production of animal-derived insulin led researchers to consider synthesising human insulin. This was achieved by inserting the insulin gene into a suitable vector, the *E. coli* bacterial cell. The insulin produced is chemically identical to the natural one. This method is more reliable, sustainable and produces human insulin in a pure form that is less likely to cause body reactions.

The industrial manufacture of insulin involves several steps:

(i) Isolation of the DNA of insulin from a human cell.

(ii) A plasmid made of DNA is removed from the bacterial cell.

(iii) A restriction enzyme cuts the plasmid from the bacterial cell open, leaving sticky ends.

(iv) The insulin gene from the human cell is added to the plasmid.

(v) The plasmid which is now genetically modified is inserted back into the bacterium.

(vi) The bacterium host cell divides and produces copies of the plasmid. The bacterium manufactures human insulin using the genes in the plasmid.

(vii) The insulin is extracted from the bacterial culture and purified.

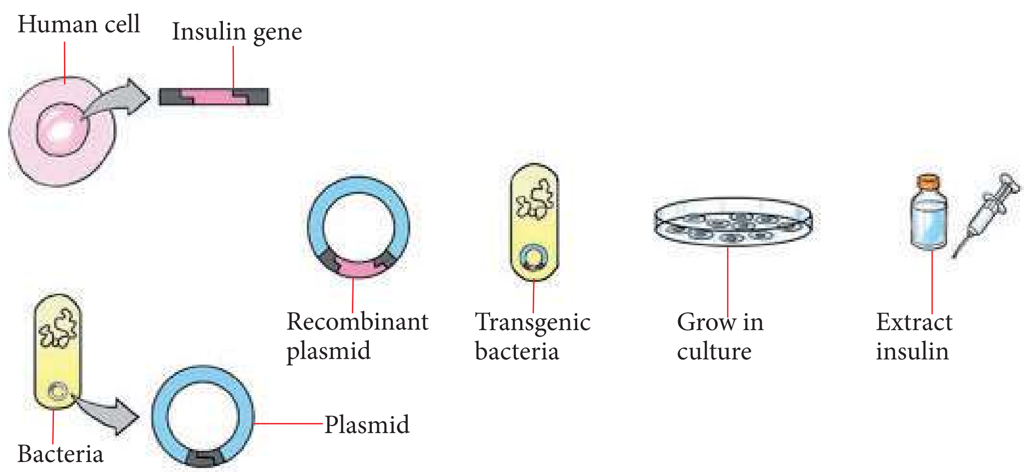


Fig 5.30: Steps of manufacturing insulin

Check your progress 5.11

1. What sort of organisms can be genetically modified?
   - A. Plants only
   - B. Plants and animals
   - C. Animals only
   - D. All of the above
2. What is genetic engineering?
   - A. Cutting the DNA code
   - B. Copying the DNA code
   - C. Changing the DNA code
   - D. Moulding the DNA code
3. True or false? The artificial crossing of two different varieties to produce a new one that has the best traits of both organisms is considered a type of genetic engineering.
4. Genetic engineering has been used to do all of the following except:
   - A. Make plants more resistant to frost.
   - B. Make plants more resistant to disease.
   - C. Make plants more resistant to herbicides.
   - D. Improve the nutritional balance of plants.

Unit 6

Adaptation and evolution

Learning outcomes

Knowledge and understanding	Skills	Attitude
• Describe how organisms are adapted to their environment, selection, evolution and evidence for it.	• Investigate fossil evidence, make observations and records to create hypotheses about evolutionary change	• Appreciate the origin and beauty of life and diversity of life forms • Value and preserve the remains (fossils) of organisms.

Introduction

Have you ever wondered why living organisms are diverse in form and behaviour, how they move, feed and adapt to different environmental conditions? Guess how early humans looked like over 10 million years ago. Guess how humans will look like another 10 millions years from now. Shall we still be able to write 10 millions years from now given the fact that computer technology is replacing the manual way of writing?

Why do you look different from your neighbour? Why do birds fly and not large mammals like elephants? How about colouration, why are you dark skinned whereas your neighbour is light skinned or vice versa? Why do giraffes browse on tree tops and not graze the way antelope do? Why is it that some diseases such as HIV and malaria can never be eradicated? Why are pest forever a problem to farmers especially in Africa in spite of regular pest control?

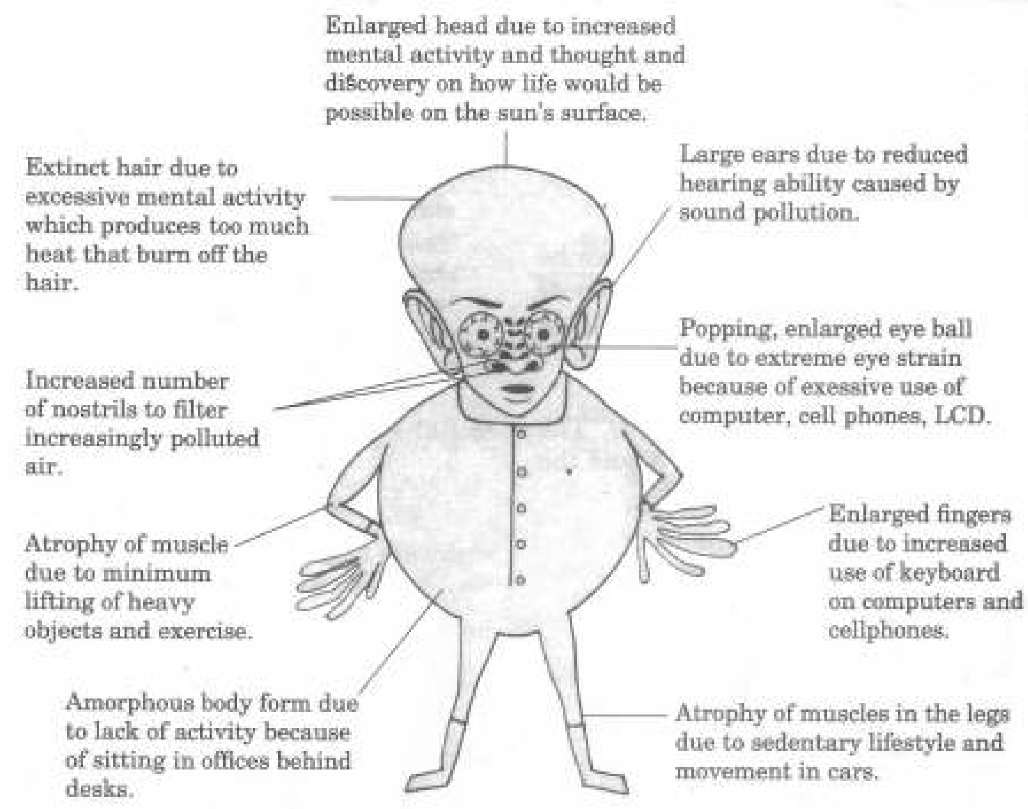


Fig 6.1: Will the human being look like this 20 million years from now?

The planet earth came into existence sometime between 4 and 5 billion years ago. Life evolved on planet earth about 3.5 billion years ago. Since then, approximately 15 million different species of organisms have evolved. But only about two million have been identified so far.

If Charles Darwin was to come to life today, what would he say about the modern person and the major changes that have taken place within human reach? Look at the major changes that has taken place over millions of years since modern person came into being, the evolution of the technology right from the first radio, to the ability of humans to fly, and to the invention of ultra-modern computers?

Imagine half human-half machine? The rise of Homo Technicans: half human and half machine!

6.1 Meaning of Biological evolution

The term evolution is formed from the word 'evolve' which means gradual change over a long period of time.

- We can therefore define biological evolution as a gradual change in the heritable characteristics of biological populations over successive generations.

- It can be described as any process of change over time.
- Classically, it is a change in the relative frequencies of heritable traits within a population across generations.
- In modern times, it is a change in the distribution of relative frequencies of genes (which code for heritable traits) within a population across generations.

Evolution is a theory, and it tries to explain how and why living organisms are diverse from unicellular organisms (e.g. bacteria) to multicellular organisms (e.g. humans).

Activity 6.1

Work in groups.

i) Visit museums and observe the ancient bone collections.

ii) Compare the ancient bone structures at the museums and the current ones you have seen from animals such as cow, goats, dogs etc. Do they look alike?

iii) Watch the movie provided on this link: https://www.youtube.com/watch?v=8SgnnV8nV9g

   a) Relate your experience to the evolutionary history.

   b) What can it tell you about evolution?

iv) You can also access photographs, pictures, books, journals and other relevant research materials to learn more on evolutionary history.

Discussion corner 6.1

Why should you study evolution? From your group and as a class, discuss the following points on why you should study evolution.

- Evolution helps us understand ourselves.
- By studying evolution, we better know our own place on a planet with 1.8 million identified species, and perhaps 10 million total species.
- We also know that all species have evolved, and that we are not the top of it.
- The context of evolution helps us know how to behave around members of our own species and members of other species.
- Evolution helps us understand the purpose and reasons for our physiology and anatomy.
- Studying evolution has helped us in the field of human health because it has equipped us to fight many diseases. This is known as evolutionary medicine, a topic that will be discussed more later in the course. An example of evolutionary medicine is antibiotic resistance to penicillin.
- The drug was mass produced around 1943, and by 1947 the bacteria it was created to kill had begun to develop a resistance. The same is true of rapid evolution of the resistance of HIV to the 3TC drug today.

- Evolution is a major part of the planet's food supply.
- The Green Revolution has led to a widespread application of monoculture crops, now including genetically modified organisms. Due to their genetic similarity, pests (weeds, insects, and pathogens) could take out entire crops.
- Evolution comes into play as pests develop resistance to the insecticides and herbicides used to combat them.
- Humans must acknowledge our own role in evolution.
- Humans have shaped the planet, and might be considered the greatest evolutionary force: Invasive Species, Habitat Fragmentation, Climate Change, Rapid Hybridization, Reduced Gene Flow, Many populations move etc.

My environment, my life!

- Can the history of evolution help us live together in harmony?
- The understanding that we come from a common ancestry?
- That despite the fact that our mother tongue differs, we are one?
- That despite the fact that our colour differs, we are one?

The facts

Terms used in evolution

Evolution: Change in the hereditary characteristics of groups of organisms over the course of generations. (Darwin referred to this process as "descent with modification.")

Species: A group of organisms of a single type that are capable of producing fertile offspring in the natural environment.

Population: All the members of a species that live in the same area and make up a breeding group.

Variation: Genetically determined differences in the characteristics of members of the same species.

Natural selection: Greater reproductive success among particular members of a species arising from genetically determined characteristics that confer an advantage in a particular environment.

6.2 Theories about origin of life

Several theories have been put forth to explain the origin of life. Among the many theories, there are chemical and biological theories. However, the many held views about the origin of life are listed below:

a) **Special creation:** Life was created by a supernatural being within a particular time.

b) **Spontaneous generation:** That life originated from non-living matter all at once e.g. maggots arise from decaying dead organic matter.

c) **Steady state:** That life has no origin.

d) **Cosmozoan:** That life on earth originated from elsewhere, i.e. the outer space.

e) **Bio-chemical evolution:** That life originated according to chemical and physical laws.

Only special creation and chemical evolution will be discussed.

Discussion corner 6.2

From your religious point of view, do you believe in evolution?

i) Explain to your classmates how life came about from your understanding

If not sure, ask your parents /or grandparents prior to the class discussion what your family point of view is.

ii) Do you agree with other theories of creation other than your own/family point of view?

Special creation

Special creation is a theological doctrine which states that the universe and all life in it originated in its present form by unconditional fiat or divine decree.

- Divine decree is from a supernatural being-God.
- The earliest idea is that of special creation which is recorded in the Bible and Koran and other religious books whereby God powered the earth and all living organisms were created. Acceptance of special creation is by faith. There is no scientific evidence for it.
- By faith we understand that the universe was created by the command of God.
- Since all living organisms are of divine origin, they are permanent and non-changeable entities that exist in the same form in which they were created initially.

Chemical theory of evolution

This theory states that life might have originated at first on earth through a series of combinations of chemical substances in the distant past and it all happened in water.

The chemosynthetic theory of origin of life was proposed by A.I. Oparin. The earth originated about 5 billion years ago. It was initially made up of hot gases and vapours of various chemicals. Gradually it cooled down and a solid crust was formed. The early atmosphere contained ammonia (NH3), water vapor (H_2O), hydrogen (H_2) an d methane (CH_4). At that time there was no free oxygen. Heavy rains fell on the hot surface of earth, and over a very long period the water bodies appeared that still contained hot water. Methane and ammonia from the atmosphere dissolved in the water of the seas. In this water, chemical reactions occurred and gave rise to amino acids, nitrogenous bases, sugars and fatty acids which further reacted and combined to give rise to biomolecules of life such as proteins and nucleic acids.

- The chemosynthetic theory implies that the development of life is probable wherever the proper physical and chemical conditions are in place.
- It also implies that all life on Earth evolved from a common cellular ancestor.

Discussion corner 6.3

a) Do you believe that life arose from chemical reactions that gave rise to biomolecules such as proteins and nucleic acids?

b) Imagine what the situation would be like if you perform a simple experiment and instead a living organism arises as a result!

Check your progress 6.1

1. Why do we study evolution?
2 List four theories of the origin of life.
3. Briefly explain special creation theory
4. Explain how chemical evolution could have led to the formation of the first simple cell.

Organic evolution

Evolution according to organic theory is the formation of complex organisms through 'gradual change' from simple ancestral types over the course of geological time.

The theory of organic evolution states that "All living things on earth are here as a result of descent, with modifications from a common ancestor."

According to the theory of organic evolution:

a) The various present day organisms were not created in the same form in which they exist today, but have gradually evolved from much simple ancestral forms from a common ancestor.

b) The characteristics of organisms had been changing in the past; they are changing even today, and will continue to do so in the future as well. This is due to the fact that the environment in which organisms live also changes, and organisms need to adapt to the changed environment in order to survive.

c) Several living organisms of the past have become extinct.

d) The origin of the various forms (species) found on earth has been a gradual and extremely slow process, requiring hundreds or even thousands of years. However, the evolution of black peppered moth or polyploid varieties of some crops or pesticide resistant mosquitoes happened in much shorter periods of time.

Evidences for organic evolution

What is evidence? You have observed that mangoes are only sweet when ripe, but what tells you that they are indeed ripe and ready to eat? Most probably the coat colour; when they turn yellow from green. Hence the evidence that the mangoes are ripe is the yellow coat colour. However, you may find later that not all mangoes that turn yellow are sweet, some could still be acidic. The proof is theoretised as evidence for a relationship, i.e. "yellow coloured mangoes are ripe." In the same way, before scientist proposes a theory of evolution and its mechanisms, they needed some proof or evidence for it.

Discussion corner 6.4

What is the evidence that:

i) It is day break in the tropics?
ii) Bananas are ripe?
iii) The family cow has milk?
iv) Your grandmother's hen will soon hatch chicks?
v) A given substance is acidic from your chemistry lab activity?
vi) That your little sister/brother could be developing a fever?
vii) The dry cell has power?

The evidences supporting organic evolution are derived from a number of fields of Biology. They include:

a) Morphological evidences
b) Embryological evidences
c) Paleontological evidences
d) Molecular evidences

a) Morphological evidences

Though organisms of different species and groups are quite different from each other, they still retain certain common features. Morphological evidences for evolution are derived from:

(i) Homologous and analogous organs
(ii) Vestigial organs
(iii) Connecting links

Homologous organs

Homologous organs are the organs which are similar in structure and origin but may look very different and perform different functions.

- Forelimbs of vertebrates are a good example of homologous organs. They are built on the same fundamental plan, yet they appear different and perform different functions.
- In each case the forelimb consists of humerus, radius and ulna, carpals, metacarpals and phalanges (see Figure 6.3).
- This basic similarity in the structure of the apparently different forelimbs of different kinds of vertebrates is due to the fact that all these limbs have evolved from a common type called the pentadactyl (five-fingered) limb.

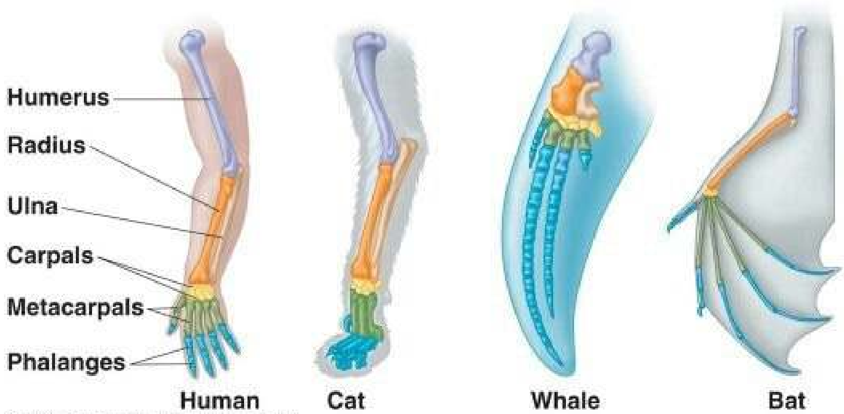


Fig 6.2:Homologous organs

Do the homologous organs, therefore, prove that different kinds of organisms came into existence through evolution?

b) Embryological evidences

Embryology is the study of development of an organism.

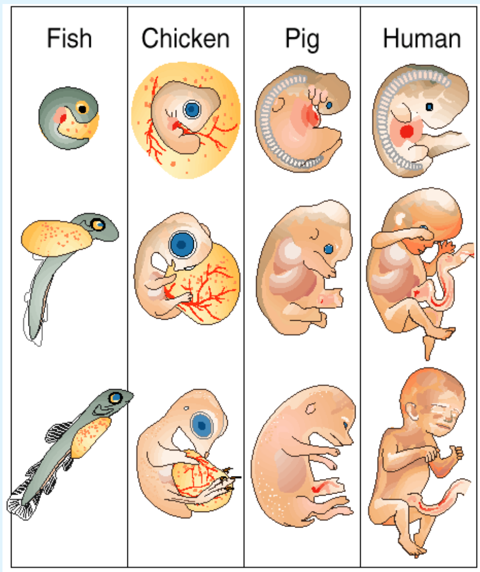
The aspects of embryology which support the doctrine of organic evolution are:

- Similar stages of early development (morula, blastula or gastrula) in all the animals.
- The embryos of all vertebrates are similar in shape and structure in their early stages. This resemblance is so close that it is difficult to tell them apart.
- All the vertebrates start their life from a single cell, the zygote.
- All of them, during their life history, pass through two-layered blastula and three layered gastrula stage and then through fish-like stage with gill-slits. All the different aspects of embryology strongly support the fact that the different classes of vertebrates had common ancestors.

Activity 6.2: Embryology

Work in groups.

From the photos provided, compare and contrast various stages of development between a fish, birds, pig and human.



Study questions

i. What is common among the stages?

ii. What is your conclusion from the observation?

c) Evidences from Paleontology (Fossil records)

Paleontology is the study of fossils.

- Fossils are the remains or traces of animal and plant life of the past, found embedded in rock either as petrified hard parts or as moulds, casts or tracks.
- Fossils are contained in rocks which build up in layers called strata. The strata provide a sort of timeline with layers found at the top indicating newer and layers at the bottom indicating older extinct species. Fossils help us document the existence of now extinct species which shows that different organisms lived on earth during different periods of planet's history.
- The fossils of the earliest era in the geological time scale were those of bacteria, then invertebrates and then successively of fishes, amphibians, reptiles and lastly of birds and mammals, and among mammals primitive fossils of humans are the most recent.

Fig 6.3: Fossils of earliest era

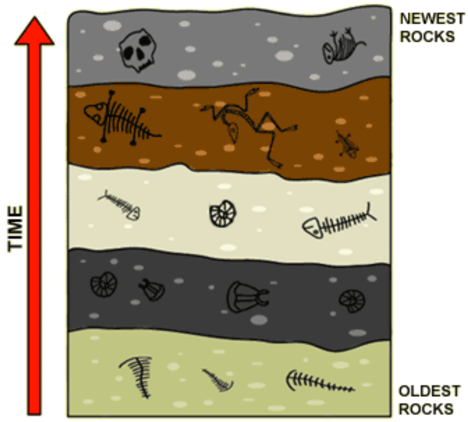


Fig 6.4: Fossils contained in rocks

d) Molecular evidence of evolution

- All organisms have a cell as the basic unit of life. The cell is made of biomolecules common to all organisms.
- Ribosomes, the cellular organelles, are of universal occurrence in organisms.
- DNA is the hereditary material of all organisms, except for some viruses.
- ATP is the molecule which stores and releases energy for biological processes.
- The same 22 amino acids form the constituents of proteins of almost all organisms.
- The genetic code is universal (exceptions are very few).
- The central dogma which deals with the transfer of genetic information in cells is the same.
- The basic steps of transcription and translation for protein synthesis are similar in all organisms.

- The sequence of nucleotides such as that for the promoter gene (TATA box) is common to all organisms.

Did you know?

That organisms that share same chemical characteristics show closer evolutionary relationships. For example,

(i) Human blood proteins are most similar to those of the chimpanzee among all apes.

Mechanisms of evolution

It discusses how evolution occurs.

Two key theories shall help you explain the mechanisms of evolution:

Darwins theory and **Lamarck's theory** of evolution.

Various theories about the mechanism of evolution have been proposed; some of them such as Lamarck's theory of 'Inheritance of acquired characters' and De Vries' theory of 'mutation' are now of historical importance only. **Darwin's theory of natural selection** still holds ground but was modified with progress in genetics and developed into the **Modern synthetic theory** which is regarded as the most valid theory of evolution.

These theories were supported by mechanism of evolution such as:

- Mutation
- Genetic drift
- Gene flow
- Non-random mating
- Natural selection

Mutation

Evolution by **mutation** occurs whenever a mistake in the DNA occurs in the heritable cells of an organism. In the single-celled asexual organisms such as bacterial, the whole cell and its DNA is passed on to the next generation because these organisms reproduce via binary fission. For sexual organisms, mutations are passed to the next generation if they occur in the egg or sperm cells used to create offspring. Mutations occur at random in the genome, but mutations of large effect are often so bad for the organism that the organism dies as it develops, so mutations of smaller effect or even neutral mutations are theoretically more common in a population. The variation that is created in a population through the random process of mutation is called **standing genetic variation** and it must be present for evolution to occur. Mutation is the raw stuff of evolution because it creates new heritable phenotypes irrespective of fitness or adaptation.

Genetic drift

Evolution by **genetic drift** occurs when the alleles that make it into the next generation in a population are a random sample of the alleles in a population in the current generation. By random chance, not every allele will make it through, and some will be overrepresented while other decline in frequency regardless of how well those alleles encode for phenotypic suitability to the environment, so sometimes drift reduces the average fitness of a population for its environment.

Gene flow (migration)

Two different populations are often subject to different selective pressures and genetic drift, so they would be expected to have different allele frequencies. When individuals from one population migrate into a different population, they bring those different allele frequencies with them. If enough migration and mating occurs between two populations, then the two populations will experience changes in allele frequencies such that their allele frequencies become similar to each other.

Non-random mating results

Selecting a mate at random is a pretty risky idea because half of the offspring's genes come from your mate. **Non-random** mating is a more common approach in real populations: think about male birds being selected as mates by females who choose males for their vivid colouration or beautiful and complex birdsong. There is evidence that fish, birds, mice and primates (including humans) select mates with different genotypes than themselves.

Discussion corner 6.4

Consider these scenarios:

i. Your father breaks a limb and because the limb was not fixed well, he develops a limp; when you are born you also develop a limp like your father.

ii. Your mother pierces her ears for beauty, when you are born your ears are already pierced.

iii. Your mother has had a scar on her left wrist since childhood, you are however without a scar at birth.

Question: What can you say about the three scenarios?

Modern evolutionary theory

The incorporation of genetics and Darwin's theory is known as "modern evolutionary synthesis."

- The physical and behavioural changes that make natural selection possible happen at the level of DNA and genes. Such changes are called mutations.
- It supports Darwin's concepts of variation and natural selection.
- It is based on information provided by modern research describing mechanisms of genetic inheritance.
- It incorporates the genetic basis of variation in individual organisms and populations.

According to this theory:

a) The unit of evolution is 'population' which has its own gene pool. Gene pool is the group of all different genes of a population.

b) Heritable genetic changes appear in the individuals of a population.

c) These heritable changes or variations occur due to small mutations in the genes, in the chromosomes and their recombination.

d) Natural selection selects the variations which helps in adapting to the environment.

e) A change in the genetic constitution of a population selected by natural selection is responsible for evolution of a new species, since through interaction of variation and **natural selection** more offspring with favourable genetic changes are born. This is called 'differential reproduction'.

f) Once evolved, **reproductive isolation** helps in keeping species distinct.

6.3 Natural selection

Natural selection is also one of the theories that seeks to explain how species arose from pre-existing species. Look around you and you will realise that living organisms live and die in accordance to their ability to survive in that environment. Natural selection is the struggle of organisms to survive and reproduce within a given environment.

Note: It is a mechanism for change in populations. This means that it occurs when organisms with favourable traits survive, reproduce and pass on their variations to the next generation.

The main points of the Darwin-Wallace Theory of Evolution

i) **Overproduction** – produce more offspring than needed because only a few will survive.

ii) **Competition** – offspring must compete for food, water and shelter so only a few survive.

iii) **Variation** – differences in individuals. Some may affect the ability to compete.

The theory of evolution by natural selection

a) Variations occur in every species: All living things consist of a unique combination of chemicals organised in unique ways, i.e. variations occur in every species and no two individuals of a species are alike.

Fig 6.5: Variation in butterflies

b) Species' populations are able to adapt to gradually changing environments. The same species in different parts of the world have different tolerances and slightly different characteristics to survive the local conditions in which it lives, e.g. live oak in Austin versus live oak in Baton Rouge; flower and gardening catalogues versus local growers. They are still the same species and interbreed naturally where they come into contact.

c) Most of these variations have a genetic basis!

They can be passed on to their offspring. Darwin was not aware of Mendel's work; he didn't know how traits were passed on, just observed that some were

It took another 50-60 years before hereditary information was added to Darwin's original theory, which made it even more powerful.

d) **Population size:** Each species produces more offspring than will survive into maturity e.g mice will produce more offsprings but a few will survive to maturity.

e) **Survival of the fittest:** Those individuals whose variations best fit their environment will be more likely to survive and reproduce fitness i.e. the ability to reproduce organisms with less favourable variations will be less likely to survive. There is a "struggle for existence" with "survival of the fittest".

f) By a process of natural selection, evolution sorts through these numerous variations within a population and "chooses" the most fit combination. As the environment slowly changes and certain variations are selected, over 100's or 1000's of generations later new forms will arise.

1. Traits, which are beneficial to the survival of an organism, are retained and passed on, therefore an increase in frequency.
2. Traits, which have a low survival value to organisms, tend to diminish in frequency.
3. If environmental conditions change, traits that were formerly associated with a low survival value may, in a changed environment, have a greater survival value and increase in frequency.

   An example of this would be:

   a) Roaches, mosquitoes and flies becoming resistant to insecticides.

   b) Widespread use of antibiotics has caused some bacteria to become resistant to the drugs.

   c) Malaria parasites. Plasmodium species, have developed resistance to malaria drugs over the years.

Evolution's role in history

Activity 6.3

Work in pairs.

Find out how scientific ideas paved the way for Darwin's theory of natural selection, and how his theory changed the course of not just science, but also the world.

Check your progress 6.2

1. What is the meaning of the word evidence?
2. List four evidences of organic evolution.
3. What is a fossil record?

Natural selection process and evolution

Natural selection leads to evolutionary change when individuals with certain characteristics have a greater survival or reproductive rate than other individuals in a population and pass on these inheritable genetic characteristics to their offspring.

Darwin's Theory of Evolution via Natural Selection

a) **Species change over time**: Some traits become more common, others less. This process of change is driven by natural selection. The traits that become more common are the ones that are "adaptive" or "increase fitness" (that is, a creature's chances of living longer and producing more offspring). Example: the long neck of giraffes.

b) **Speciation occurs:** The process described in a) continues to the point where descendants eventually constitute a different species from their remote ancestors. New species evolve from older ones.

c) **The common ancestry of different species:** The common/shared ancestors of more closely related species (e.g. lions and tigers) are more recent than the shared ancestors of less closely related ones (e.g. tigers and humans). But we'll find a common ancestor for very dissimilar species, like humans and flies, if we go back far enough.

c) Role of reproductive isolation

Once new species arise from the parental species due to the effect of variation and natural selection, reproductive barriers prevent the two species from exchanging genes through reproduction.

Thus two related species cannot mate with each other and remain distinct. Isolation means separation and reproductive isolation simply means that the two species are prevented from successful reproduction and kept genetically distinct from each other. Reproductive isolation operates in the following ways:

Isolation	Impact
Ecological isolation	The two species are unable to mate as they live in geographically different areas.
Seasonal isolation	Mating is prevented because the reproductive organs mature at different times.
Ethological (behavioural)	The songs in birds of two species or the colouration isolation of two fishes are so different that the female of one species is able to recognise only the male of its own species.
Mechanical isolation	The male and female organs for mating differ in different species and prevent their union.

Isolation	Impact
Physiological isolation	The sperms of one species are not able to survive in the female tract of another species.
Zygotic and developmental isolation	If all the above mechanisms fail and a "hybrid zygote" (zygote from mating of two different species) is formed, it dies after some time. If the hybrid zygote survives, it dies during development.
Hybrid sterility	Mule, the offspring of a female horse and male donkey, is a good example. It leads a normal life but is sterile and cannot reproduce.
F_2 breakdown	In rare cases, all the above mechanisms fail and a hybrid (offspring of parents belonging to different species) is fertile, it can reproduce only for one generation.

Evolution of new species

The evolution of new species is known as **speciation**. Speciation occurs in the following ways and is termed accordingly.

Evolution work on different scales

Evolution encompasses changes of vastly different scales, e.g. from something as insignificant as an increase in the frequency of the gene for dark wings in beetles from one generation to the next, to something as grand as the evolution and eradication of the dinosaur lineage. These two extremes represent classic examples of micro and macroevolution.

Microevolution happens on a small scale (within a single population), while macroevolution happens on a scale that transcends the boundaries of a single species. Despite their differences, evolution at both of these levels relies on the same established mechanisms of evolutionary change.

6.3.4.1 Microevolution

Microevolution is simply a change in gene frequency within a population. Evolution at this scale can be observed over short periods of time, for example between one generation and the next, the frequency of a gene for pesticide resistance in a population of crop pests increases.

Such a change might come about because:

i) Natural selection favoured the gene.

ii) The population received new immigrants carrying the gene.

iii) Some nonresistant genes mutated to the resistant version.

iv) Random genetic drift from one generation to the next.

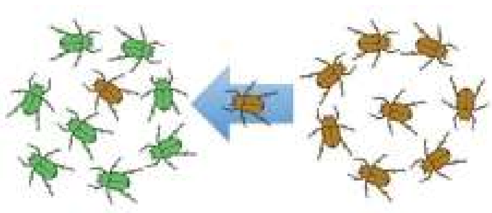


Fig 6.6: Microevolution.

Evolving resistance

Science has documented many examples of the evolution of resistance of pests to pesticides, weeds to herbicides and pathogens to medicines, all of which are cases of microevolution by natural selection.

- In the case of antibiotic resistance, for example, a bacterial strain's huge population size and short generation time mean that natural selection acts quickly. In each bacterial generation, new mutations and gene combinations are generated. If any of these confer resistance to a drug to which the bacteria are exposed, natural selection will favour those gene versions.
- Over the course of many bacterial generations (a small fraction of a single human lifetime), the bacteria adapt to our defences, evolving right out from under our attempts to rid ourselves of them.

  This general scenario has played out many, many times. Just a few examples include:
  - Mosquitoes evolving resistance to DDT.
  - Whiteflies evolving resistance to pesticides.
  - Gonorrhea bacteria strains evolving resistance to penicillin.
  - HIV strains evolving resistance to antiviral medicines.
  - Malaria parasites evolving resistance to treatment.

Macroevolution

Macroevolution refers to evolution above the species level. Instead of focusing on an individual e.g. beetle species, you instead focus on the tree of life, to assess the diversity of the entire beetle clade and its position on the tree.

- Macroevolution encompasses the grandest trends and transformations in evolution, such as the origin of mammals and the radiation of flowering plants.

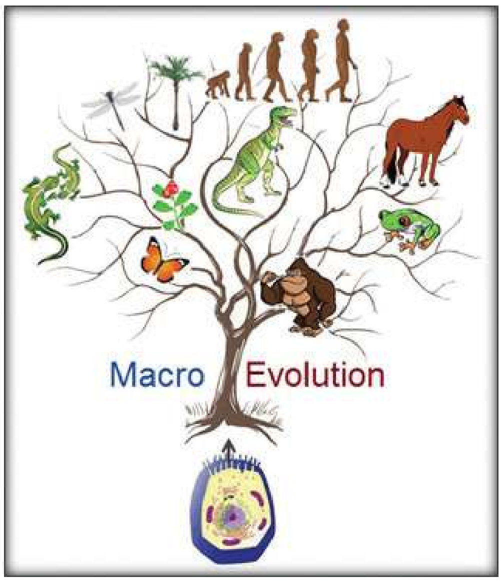


Fig 6.7: Macroevolution

Vestigial organs

Vestigial organ is any small degenerate or imperfectly developed (non-functional) organ or part which may have been complete and functional in some ancestor.

Look at the images of the vestigial organs provided e.g. human hair, appendix, wisdom teeth, tail vertebrae.

The only rational explanation for the presence of these non-functional organs is that they have been inherited from ancestors from whom they were functional. Fig. 6.9 shows some of the vestigial structures in the human body.

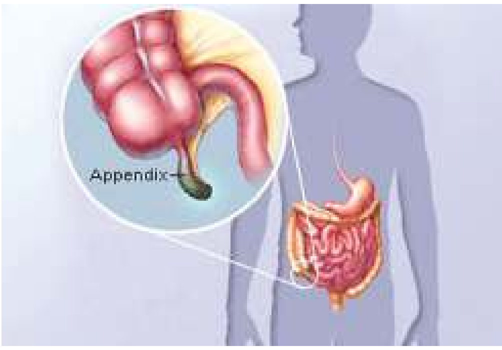


Fig 6.8: Vestigial organ

6.4 Convergent and Divergent evolution

How do new species evolve?

Two types of macroevolution are speciation (or divergent evolution) and convergent evolution.

- **Speciation** or **divergent evolution** occurs when two separate species evolve differently from a common ancestor.
- **Convergent evolution** occurs when species have different ancestral origins but have developed similar features. A good example of convergent evolution is the similarities between the hummingbird and the hummingbird moth.

Convergent evolution

Convergent evolution is the process in which species that are not closely related to each other independently evolve similar kinds of traits.

For example dragonflies, hawks and bats all have wings. However, none of these organisms owes its wings to genes inherited from any of the others. Each kind of wing evolved independently, suggesting that the trait of flight is a useful one for the purpose of survival and reproduction. These independently evolved wings are called **analogous structures**.

Activity 6.4

a) Compare shells of turtles and snails. State whether they are convergent or divergent evolution.

b) Compare the wings of bats and pigeons and state whether they convergent or divergent.

c) Compare the tails of a shark and whale and state whether they are convergent or divergent.

Divergent evolution

Divergent evolution is the process in which a trait held by a common ancestor evolves into different variations over time. A common example of divergent evolution is the vertebrate limb. Whale flippers, frog forelimbs and your own arms most likely evolved from the front flippers of an ancient jawless fish. Because they share a common evolutionary origin, these are examples of **homologous structures**.

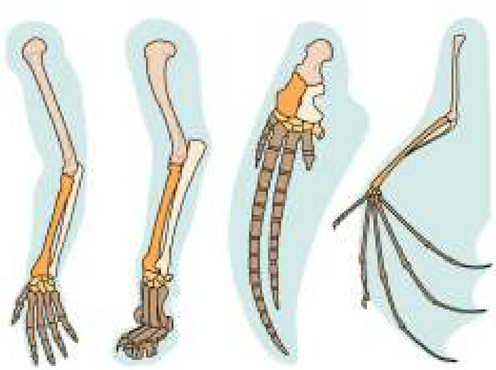


Fig 6.9: Homologous structures

An important consequence of divergent evolution is speciation, the divergence of one species into two or more descendant species.

Two major ways speciation can occur: **allopatric** and **sympatric speciation**.

- **Allopatric speciation** occurs when a population becomes separated into two entirely isolated subpopulations. Once the separation occurs, natural selection and genetic drift operate on each subpopulation independently, producing different evolutionary outcomes.
- **Sympatric speciation:** Sometimes a genetic barrier (reproductive barrier) prevents reproduction between a section of a population of a species with other members. Such a section of population usually arises in plants because of polyploidy. **Polyploidy** is a mutation in which the normal diploid number of chromosomes become doubled or trebled (2n becomes 3n, 4n, 5n etc.) in a section of the population of a species due to certain irregularities during cell division. The polyploid section of the population is then unable to interbreed (mate and reproduce) with their diploid ancestors and becomes a new species.

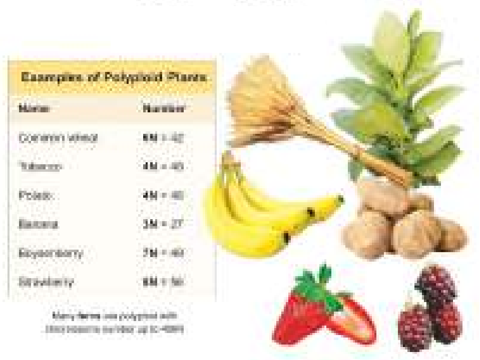


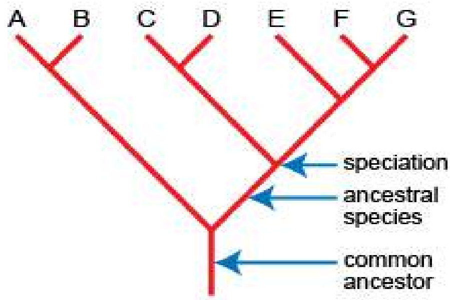
Fig 6.10: Polyploidy

6.5 Evolutionary processes that lead to the tree of life

- The process of evolution produces a pattern of relationships between species. As lineages evolve and split and modifications are inherited, their evolutionary paths diverge. This produces a branching pattern of evolutionary relationships.
- By studying inherited species' characteristics and other historical evidence, we can reconstruct evolutionary relationships and represent them on a "family tree" called a phylogeny. The phylogeny you see below represents the basic relationships that tie all life on Earth together.

The three domains

- This tree, like all phylogenetic trees, is a hypothesis about the relationships among organisms. It illustrates the idea that all of life is related and can be divided into three major clades, often referred to as the three domains:
- Archaea, Bacteria and Eukaryota. We can zoom in on particular branches of the tree to explore the phylogeny of particular lineages, such as Animalia (outlined in red).
- We can then examine some of the major lineages within Vertebrata.



6.6 Natural selection and adaptation

According to Charles Darwin's theory of evolution by natural selection, organisms that possess heritable traits that enable them to better adapt to their environment compared with other members of their species will be more likely to survive, reproduce and pass more of their genes on to the next generation.

Definition of adaptation

An **adaptation** is a characteristic that helps an organism survive in its environment or reproduce.

An adaptation is any kind of inherited trait that improves an organism's chances of survival. Because of variations, some individuals will be better adapted to survive and reproduce than others. These individuals are the fit.

Why do living organisms evolve?

Living organisms evolve in order to adapt to the ever changing environmental conditions.

Activity 6.5

1. Look at the pictures below.

2. What do you think the animals listed in 1 feed on?
3. Now go out and collect an acacia leaf, a stinging nettle and cactus.

The facts

The type of teeth and beaks found in different animals reveals more on the diet and feeding methods of the animal. For example, lions have canines that enable them to pierce and hold food. Zebra's teeth are well adopted for chewing grass while bird's beak are adapted for picking grain.

Importance of adaptation

A characteristic that makes an individual better suited to a specific environment may eventually become common in that species through natural selection.

i) Individuals whose unique characteristics are well-suited for an environment tend to survive and produce more offspring. Offspring then inherit these traits, which results in adaptation.

ii) Adaptations allow animals and plants to live successfully in their habitat, e.g. help get the food they need, to communicate with each other, and to avoid predators.

iii) Because habitats are different, animals living in different habitats need different adaptations – compare the polar bear and the camel.

Activity 6.6

Work in pairs.

Study the pictures below carefully.

1. Identify from the two pictures the predator and the prey.
2. Share with your friend how preys are adapted to escape from predators.
3. Why do you think most prey and predators move in large numbers? Explain.
4. How are the feet of both prey and predator adapted to running?
5. Share with your friend how different animals are adapted to escape from their predators.

Prey adaptations

- Many animals have adaptations for the same reason – to escape from predators. No one wants to be eaten!
- In a group, there is safety in numbers. This is why many land animals such as zebras and Thomson's gazelles form herds.
- You could also have physical defenses – for example sea urchins have hard spines that stop predators from eating them.

Predator adaptations

If you are a predator, then you need adaptations that make it easier for you to catch your prey. Predator adaptations include:

- You could hunt in a group and work together, like emperor penguins do.
- You could use poison to subdue your prey, like the sea snake.
- Or you could be like the most effective sea predator of all, the shark, and have huge teeth!

Activity 6.7

1. In your local environment, observe different birds, animals, plants and insects. Check on the following:
   - Where you think the birds, animals, plants and insects live (its habitat)?
   - What types of food do the organisms above feed on?
   - How does the bird, animal, plant and insect get food?

2. Complete the table below.

Bird

Birds name	Diagram	Feet Function	Diagram
Sparrow			
Eagle			

Animal

Animal's name	Diagram	Teeth Function	Diagram

Plants

Plant name	Diagram	Leaf Function	Diagram

Insect

Insect name	Diagram	Wing Function	Diagram

The facts

Types of adaptation

An adaptation is a structure or behaviour that helps organisms survive in their surroundings.

- A structure is a body part that does a certain "job".
- Activities performed by an animal that help it survive are behavioural adaptations.

Structural adaptations

a) The most obvious adaptations are those involving structure or anatomy.

b) Traits such as the structure of a bird's beak, the hoof of a horse, or the shape of a tooth, e.g. a lion's tooth, are called structural adaptations.

c) Many obvious structural adaptations in animals are for obtaining food.

Example:

a) The neck of the giraffee.

b) The slow hypothetical evolution: Response to Acacia trees.

c) Neck increased in length to reach food in trees.

Unit 7

Support and movement in plants and animals

Learning outcomes

Knowledge and understanding	Skills	Attitude
• Understand how support is provided and movement takes place in plants and animals.	• Design investigations and develop hypotheses about phototropism and geotropism in shoots and roots (radicles), make observations, record results and make judgments • Investigate the microscopic structure of the vascular system in plant roots, stems and shoots and the structure and function of bones in animals with different forms of movement.	• Appreciate the beauty of plants and mammalian internal structures.

Introduction

1. Study the pictures below and answer the questions given:

Fig 7.1: Support and movement in different living organisms

2. Can amoeba move? How about birds? At what point do plants move? What supports young plants? How do you compare bird's movement and the sprint of a cheetah? What is lacking in the wilted seedling? Look at the carnivorous plant. What can you say about its movement?

Imagine the following scenarios:

- Your arm stretches to pick up a mango or flexes to scratch the face.
- Your tongue is in motion when you sing.
- The cow drives away flies using its tail.
- A lizard's tongue is shot out to catch flying insects.
- The gill cover of the fish flips up and down to draw in a current of water.
- Cytoplasm streams within cells.

The facts

All the examples above signify movement.

When you glance around you, animals move in a unique way, foraging and at the same avoiding predation. Plants either follow the direction of the sun while plant roots move towards the water table. What makes plants grow upright and never fall?

No outside force has to 'push-start' growth of a green shoot towards sunlight or a dog to scratch, or YOU to move as you are doing right now! All these things are living, so they move by themselves!

Movement in plants and animals

All living things have the ability to move without outside help. This makes them unique from non-living organisms. Movement is a characteristic of all living organism. It is a reaction to the external environmental stimuli and it may involve part of the organism or the entire organism, as in most animals. The direction of the stimulus determines the direction of the response. Locomotion is the movement of the entire organism from one place to another. Part movement in plants is as a result of growth as a response to various stimuli. For example, plants will grow towards light and their root will grow towards water. Growth responses are usually slow and are not reversible.

Movement in animals is usually faster than growth movement in plants.

Like growth movement, they take place in response to a stimulus, but unlike growth movement, they are reversible.

The organism, or its part, can return to its original position when the stimulus is removed. Movement is important for the survival of all organisms. In animals, locomotion is important for the following reasons: finding food. Animals, unlike plants, cannot make their own food and so they have to go in search of food.

7.1 What is support and movement in plants? and animals?

The word 'support' means to 'bear the weight of an object'. In plants support is facilitated by turgidity in the cells and other specialised tissues. In some animals, support is made possible by specialised tissues that form a skeleton. In animals, support structures are necessary for movement to occur.

Need for support and movement

i) Movement is a characteristic of all living organisms.

ii) It enables animals and plants to adjust to their environment.

iii) Most animals move from place to place, but some are sessile (i.e. fixed to the substratum).

iv) Majority of plants move only certain parts.

v) However, though not easily observed, all living protoplasm shows movement of one type or another.

The facts

Need for support and movement in plants

You know that unlike animals, plants are unable to move from one place to another. This means that their needs for life are derived where they are.

Reasons why plants require support

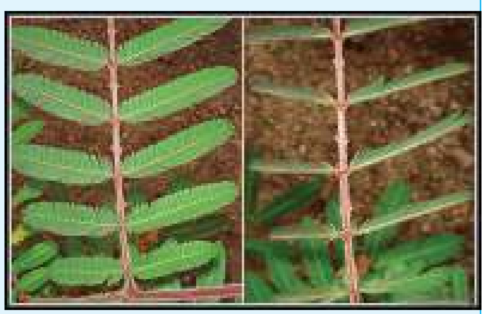
(i) Effect fertilisation and ensure perpetuation of a species.

(ii) Plant parts move in response to certain stimuli in the environment of tropisms.

Activity 7.1

Work in groups.

1) Look at the pictures below.



Discuss in groups why the above plants require support.

All the above examples indicate that most structures have either external or internal materials that hold them in an upright position i.e. giving them support.

Tissue distribution in monocotyledonous and dicotyledonous plants

Activity 7.2

Materials

- Dropper, needle, microscopic slide, cover slips, safranine, glycerin, sharp razor blade, microscope, watch glass, brush.

Procedure

1. Obtain a young root and stem of the monocot and a dicot plant.
2. Hold the plant material between the thumb and the first finger of the left hand.
3. Hold the razor blade at a right angle with its edge facing you.
4. Dip the plant material in water.
5. Cut the plant material transversely in a watch glass containing water.
6. Select the thinnest section of the plant material using a brush.
7. Put a few drops of safranine stain in the watch glass with water and leave it for 3-5 minutes.
8. Drain off the stain.
9. Place the thinnest section at the centre of the slide.

10. Put a drop of glycerine over the material.
11. Cover it with a coverslip with the help of a needle.
12. Observe it using a light microscope after staining and mounting.
13. Repeat the same procedure for the root.

A longitudinal or transverse section through a root or a stem of a monocotyledon and dicotyledon shows the following structures.

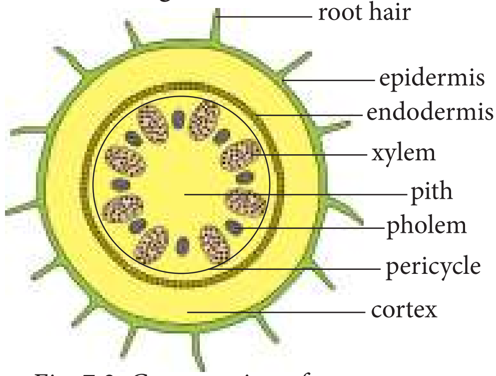


Fig. 7.2: Cross-section of a monocot root

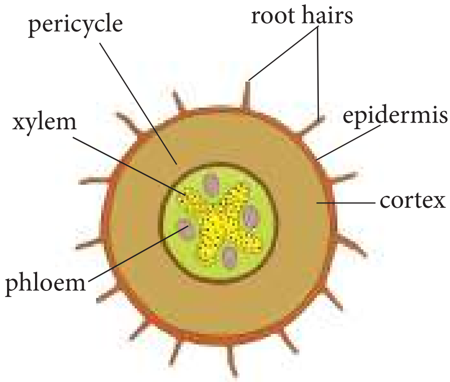


Fig 7.3: Cross-section of a dicot root

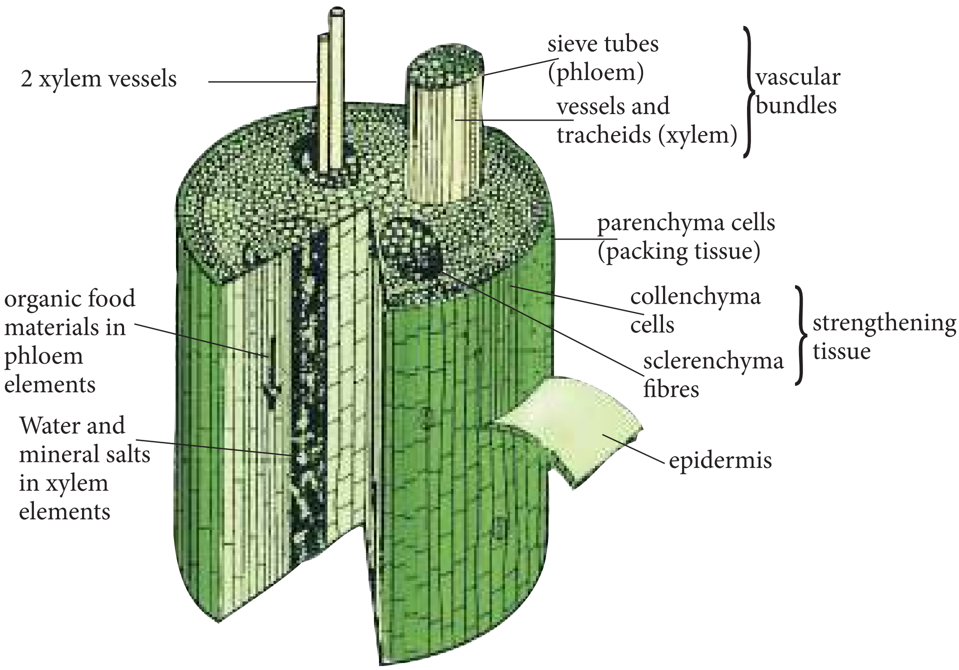


Fig. 7.4: Longitudinal section of a stem

A transverse system of the stem reveals the following structures.

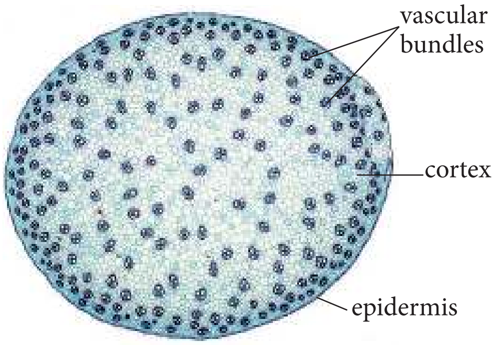


Fig 7.5: Cross-section of a monocot stem

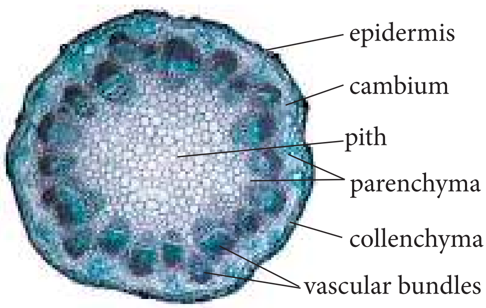


Fig 7.6:Cross-section of a dicot stem

i) Vascular bundles are the main support tissues in plants.

ii) In a monocotyledonous stem, they are scattered all over the stem.

iii) In a dicotyledonous stem, they are found in a ring or rings.

iv) In monocots, the xylem and phloem alternate around with pith in the centre.

v) In dicots, the xylem forms a star in the centre–there is no pith.

vi) Phloem is found in between the arms of the xylem.

vii) Dicotyledonous plants have cambium which brings about secondary growth resulting in thickening of the stem and root, hence providing support.

viii) Secondary xylem becomes wood, providing more support to the plant.

Role of support tissues in young and old plants

Activity 7.3

Materials

- Two containers with well watered bean seedlings or any other herbaceous plant.
- Place a container with plants out in the sun.
- Label the containers 1 and 2.
- Continue watering container 1 regularly. Do not water container 2.
- Observe the two plants for 7 days. Make sure that container 1 has holes at the bottom to drain off excess water.

Study questions

i) Describe the appearance of both plant 1 and 2 after 7 days.

ii) What name can we use to describe the condition of the plant in container 2?

iii) What has influenced the appearance of plants 1 and 2 at the end of the experiment?

iv) In which plant do you think tissues and organs are supported in their right positions?

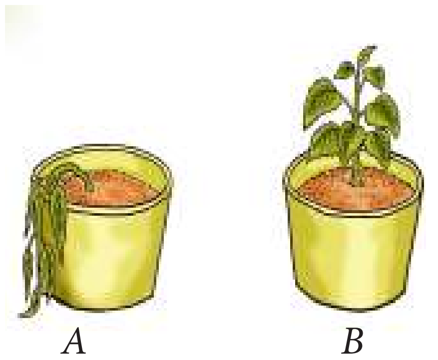


Fig 7.7

The facts

Turgidity of all the cells in the plant make the stem and leaves firm thus offering support. It makes the stem firm and erect and the leaves spread out.

i) In such a plant, all the tissues and organs are well supported in their rightful positions.

ii) Whenever plants fail to receive adequate water, they droop, hence we use the word wilt to describe such plants.

iii Wilting is common in young herbaceous plants. This is because such plants have little support tissues and depend on turgidity for support.

Support tissues in plants are tissues that have materials that make them strong and rigid so as to give support to the plant.

Plants are held upright by strengthening tissues:

a) Parenchyma

b) Collenchyma

c) Sclerenchyma

d) Xylem tissue

Parenchyma and collenchyma are the main support tissues in young plants.

a) Parenchyma

- They are found below the epidermis.
- They form the bulk of packing tissue within the plant between other tissues.
- They are tightly packed and turgid hence they provide support.

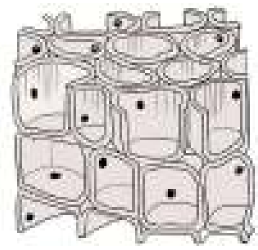


Fig 7.8: Parenchyma tissue

b) Collenchyma

- Their cell walls have additional cellulose deposited in the corners.
- This provides them with extra mechanical strength.

Fig. 7.9: Collenchyma tissue

c) Sclerenchyma

- Their cells are dead due to large deposits of lignin on the primary cell wall.
- The lignified wall is thick and inner lumen is small, hence provide support.
- Sclerenchyma fibres are arranged in elongated and in longitudinal sheets giving extra support.

- They are found in mature plants.

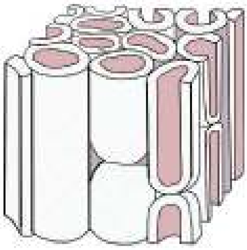


Fig 7.10: Sclerenchyma tissue

d) Xylem

- Has two types of specialised cells: Vessels and tracheids.
- Vessels are thick-walled tubes with lignin deposited in them.
- They give support and strength to the plant.
- Tracheids are spindle-shaped cells arranged with ends overlapping.
- Their walls are lignified.
- They help to support and strengthen the plant.

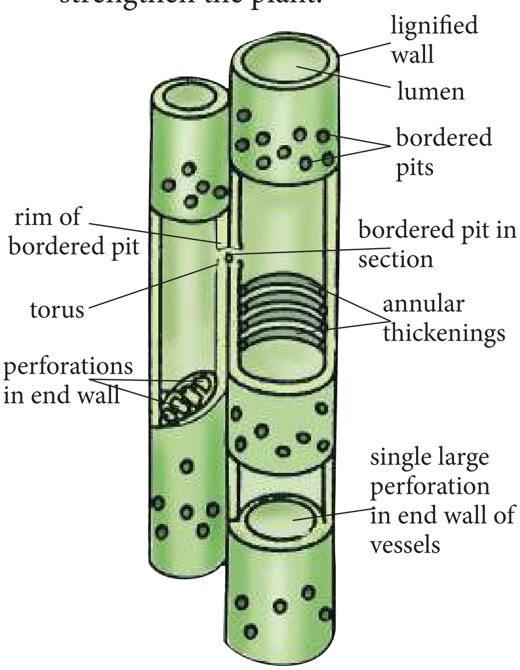


Fig 7.11: Xylem tissue

Activity 7.4

1. Observe part of a leaf under a light microscope.
2. Draw and label the parts you see.
3. Compare the image under a microscope and the one provided in Fig. 7.12. In your drawing, label:
   i) Phloem
   ii) Collenchyma
   iii) Stoma
   iv) Lower epidermis
   v) Xylem

Plants with weak stems obtain their support in the following ways:

- Some use thorns or spines to adhere to other plants or objects.
- Some have twinning stems which grow around objects which they come into contact with.
- Others use tendrils for support.
- Tendrils are parts of a stem or leaf that have become modified for twinning around objects when they gain support.
- In passion fruit and pumpkin, parts of their lateral branches are modified to form tendrils.
- In the morning glory, the leaf is modified into a tendril.

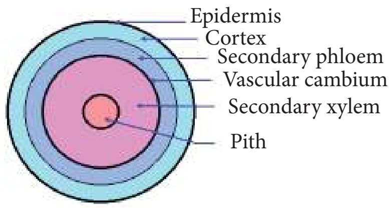


Fig 7.12: Leaf under light microscope

Check your progress 7.1

1. What is the function of vascular bundles?
2. How do plants with weak stems obtain support?
3. How do herbaceous plants obtain and maintain support?

7.2 Support and movement in plants

Unlike many animals, plant movement is non-locomotory.

- Movement is confined to specific plant parts (e.g. stems/roots) and is not always obvious because it is very slow.
- Plant movements are often related to growth.
- Tropisms are directional growth responses to an external, unilateral stimulus.
- Tropic growth movements cannot be reversed!
- Tropic growth movements are caused by chemicals called auxins that are produced in stem and root tips and cause selective cell growth and elongation which will result in either overall growth or growth curvatures of plant parts affected by the auxins.

Types of tropisms

Activity 7.5:

You will be provided with the following plants:

Mimosa pudica

Venus fly catcher

i. What happens when you touch *Mimmosa pudica*?
ii. Drop a tiny insect like a house fly inside the opening of the Venus fly catcher.

What happens as soon as the fly lands in the opening?

The facts

There are several types of tropism named after the stimulus that cause the response. They include phototropism, geotropism, thigmotropism, chemotropism, thermotropism, rheotropism and photoperiodism. More about these was discussed in Unit 3. Can you recall what you discussed.

Importance of tropism

1. Phototropism exposes the leaves to trap maximum sunlight for photosynthesis.
2. Haptotropism/Thigmotropism enables plants with weak stems to obtain mechanical support.
3. Geotropism enables roots to grow deeper into the ground and hence offer anchorage.
4. Chemotropism enables pollen tubes to grow to facilitate fertilisation.
5. Hydrotropism enables roots of the plants to search for water.

Positive versus negative tropism

Positive phototropism = positive upward growth movement in response to light.

Negative gravitropism or geotropism = negative growth movement in response to the downward pull of gravity.

Example: Shoots grow upwards, whatever the orientation of the rest of the plant.

Positive gravitropism or geotropism = positive downward growth in response to gravity.

Negative phototropism = negative growth response to light.

Check your progress 7.2

Indicate the type of tropism in the picture below.

i) Do the roots show positive or negative tropism?

ii) Do the shoots show positive or negative tropism?

Nastic movements

Can you remember what you learnt about nastic movement in Unit 3? Can you explain what nastic movement is? What about the types of nastic movement? Discuss with your friend more about nastic movement.

Importance of nastic response

i) Since nastic movements are based upon the anatomy of the plant, they may serve a protective function. As such, they help in sudden response for a change.

ii) In a lot of plants, nastic movements are associated with adaptations for cross pollination by insects and they serve to protect the flowers from conditions that they are unable to survive in. In insectivorous plants, the movements aid in the trapping of insects for food.

7.3 Support and movement in animals

Like plants, animals need to be held in the right position and to move. This movement from one place to another is referred to as **locomotion**.

Locomotion is important for the survival of an organism because it enables the organism to search for food, water, mates and more so to escape from unfavourable environmental conditions and from predators.

Need for support and movement in animals

a) In search of food.
b) To escape from predators.
c) To escape from a hostile environment.
d) To look for mates and breeding grounds.
e) The skeleton, which is a support structure, helps to maintain the shape of the body.
f) Movement is effected by action of muscles that are attached to the skeleton.

Activity 7.6: Discussion Activity

Work in groups.

i. Observe livestock grazing around. Compare chickens and goats.
ii. In your national park, observe the foraging behaviour of large and small mammals.

    Compare herbivores and carnivores.
iii. Of i and ii above, is the foraging behaviour similar?
iv. How are predators capturing their prey?
v. How are the preys evading capture?

Types of movements for locomotion

Ciliary movements

Cilia are minute hair-like processes which are motile and extend from cell surfaces. In smaller organisms like the ciliate protozoa, cilia help in locomotion from one place to another. In animals, the cilia help to propel fluids and materials. Cilia move in a pattern which is different from that of the flagellum although their internal structure is the same. Ciliary beat begins with fast stroke ahead in one direction called effective stroke and then it bends back and returns to its original position. This second stroke is called recovery stroke. During ciliary beat, water is propelled parallel to ciliated surface.

Flagella movement

A flagellum is a long, whip like structure. While cilia cover the entire surface, flagellum is mostly present singly or in a small number at one end of a cell. Flagella occur in flagellate protozoan like Euglena or an algae like Chlamydomonas and in animal sperms. A flagellum beats symmetrically in a snake-like manner and propels the water parallel to the long axis of flagellum.

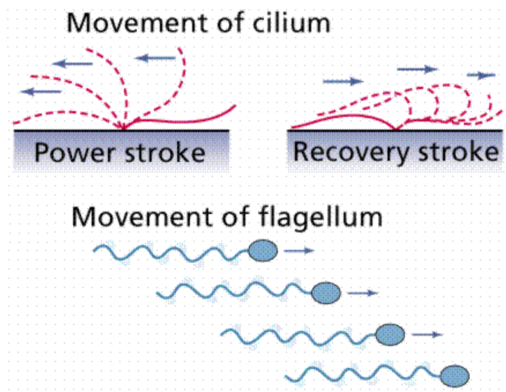


Fig 7.13: Movement of cilium and flagellum

Other movements in invertebrates

Movements in some invertebrates

There are also many invertebrates like jellyfish, earthworm and leech which are devoid of skeletons but possess muscles for their movements.

Movements in hydra

- Hydra lacks a well-developed muscular system. They have two types of contractile cells on its body wall, viz. epitheliomuscular cells in the outer layer of the body wall and the nutritive muscular cells in the inner layer. Contractions and relaxations of these cells respectively shorten and elongate their processes.
- Various types of movements seen in hydra are looping, somersaulting, climbing, shortening and elongation etc.

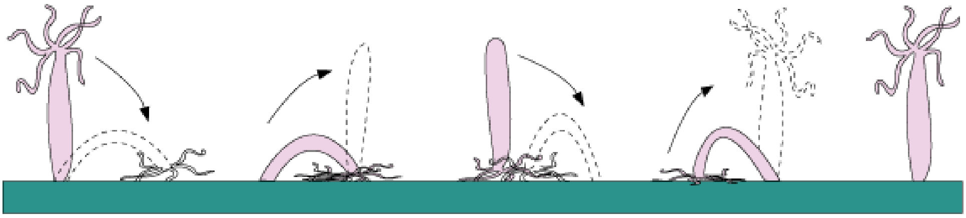


Fig 7.14: Movement of hydra

Movements in annelids

- Earthworms and leeches have muscle fibres of the body wall that help these animals to crawl on land. These muscle fibres are of two types – longitudinal muscle fibres and circular muscle fibres. In earthworms, the locomotion of the body is brought about by alternate contraction of circular and longitudinal muscles, causing waves of thinning and thickening to pass backwards. It involves partly a pushing of the anterior end and partly of the posterior end. The coelomic fluid gives turgidity as it acts as a hydraulic skeleton, making the body wall tough.
- The worm moves at the rate of about 25 cm per minute.

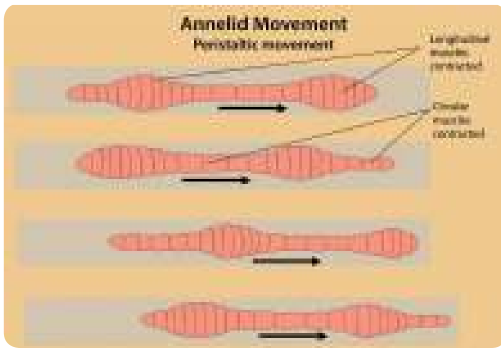


Fig 7.15: Movement in annelids

Movements in starfish

Starfishes have a water vascular system that helps them in their locomotion.

- Each arm of the starfish has two rows of tube feet underneath.
- Water enters into these tube feet by the muscular contractions and this moves the animal over the surface of the substratum in water.

- Starfishes are bottom dwellers found in sea waters only.

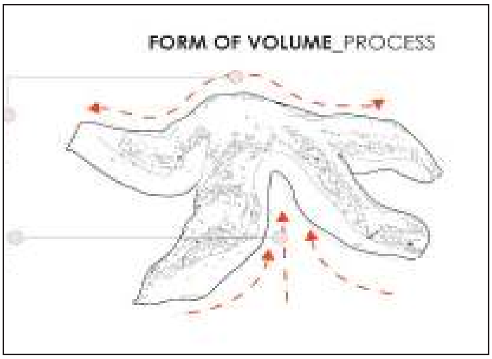


Fig 7.16: Movement in starfish

Muscular movement in animals

Structure of skeletal muscle

A whole skeletal muscle is considered an organ of the muscular system. Each organ or muscle consists of skeletal muscle tissue, connective tissues, nerve tissues, and blood or vascular tissues. Portions of the epimysium project inward to divide the muscle into compartments. Striated muscles are also called skeletal muscles as they are attached to bones and are responsible for movements of the limbs.

Striated muscle fibres are packed into bundles enclosed in a tough connective tissue. These bundles are grouped to form a muscle. Every skeletal muscle is also enclosed in a thin connective tissue as shown in Fig. 7.24. The ends of muscles connect to bones through another kind of connective tissue called tendon. So, the tendon joins a bone to a muscle.

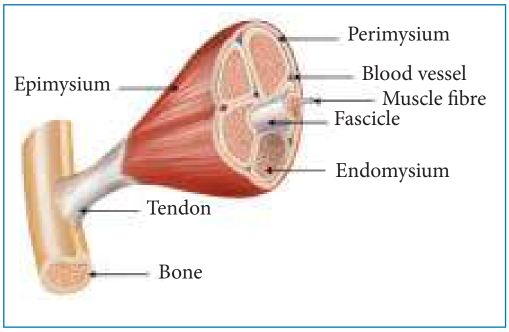


Fig 7.17: Structure of a skeletal muscle

Myofilaments

The muscle cell, also called muscle fibre because of its long shape, is multinucleated and contains myofibrils made of myofilaments. Myofilaments are proteins which are of two types:

(i) thick filaments made of myosin protein and

(ii) thin filaments made of actin protein.

Myosin and actin proteins are contractile proteins and are responsible for muscular contraction. The functional unit of the myofibril is called sarcomere. It lies between two successive dense linear structure called Z lines. The thin filaments also contain two other proteins, tropomyosin and troponin. Troponin is the switch, which in the presence of calcium ions controls muscle contraction.

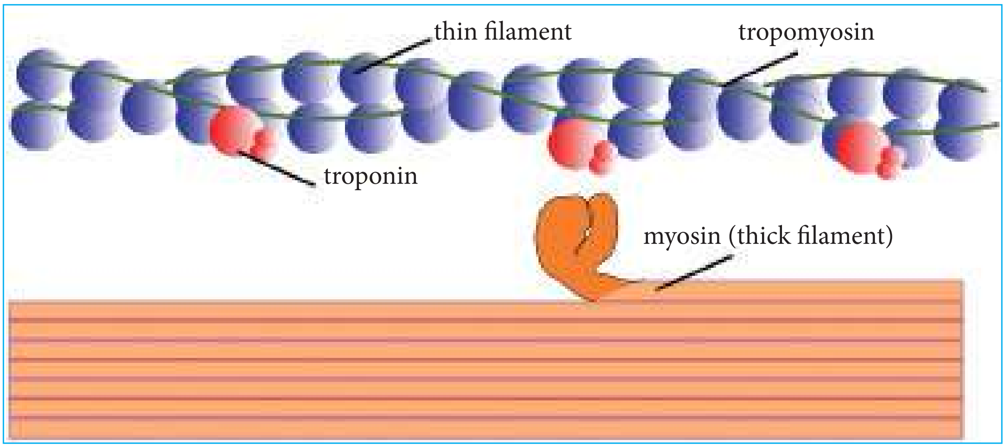


Fig 7.18: Molecular structure of thick and thin myofilaments of a skeletal muscle

The sliding model of muscle contraction

Striated muscle contraction is explained by s**liding filament theory**. This theory can be explained through the following steps:

(i) The thick and thin filaments, myosin and actin, are linked by cross bridges of troponin and tropomyosin.

(ii) These cross bridges, on contraction, pull the thin filaments back over thick filaments.

(iii) As a result, the thin filaments slide over the thick filaments. Calcium and ATP are required for attaching and releasing troponin.

(iv) Because of this sliding action, Z lines come closer and sarcomere shortens.

(v) All sarcomeres shorten together so the entire muscle contracts.

(vi) The muscle relaxes when cross bridges relax and sarcomere regains original position.

Stimulation of muscle contraction

Muscles cannot contract on their own unless stimulated by a nerve. The nerve branches on a muscle and this area of the muscle fibre is called myoneural junction (myo: muscle; neuro: nerve).

Summary of biochemical events of muscle contraction

i) Nerve impulse arrives at neuromuscular junction (neuron to muscle cell communication).

ii) Acetylcholine (ACh) is released from motor neuron and diffuses across to the motor end plate.

iii) ACh binds with nicotinic receptors at the motor end plate (a specialised portion of sarcolemma). Receptors are linked to ligand gated ion channels, allowing Na+ influx (plus a little bit of K+ efflux), resulting in the depolarisation of the muscle cell membrane. This results in a motor end plate potential, which becomes an action potential (AP) in muscle cells.

iv) The impulse (AP) is spread very quickly throughout the cell by the transverse (T) tubules. Located on the T-tubules are the dihydropyridine (DHP) receptors that are mechanically linked to the lateral sacs (terminal cisternae) of the sarcoplasmic reticulum (SR). When triggered by the change in membrane potential (AP) traveling down the t-tubules, the DHP receptors mechanically opens gates on the SR. This then causes the SR to release the Ca^{2+} it has stored there into the cytosol (sarcoplasm) of the skeletal muscle.

v) The increase in $[Ca^{2+}]i$ binds to the regulatory protein troponin, causing it to change shape and move.

vi) The movement of troponin then moves tropomyosin away from covering the active site on actin, thus exposing the myosin binding site on actin.

vii) Due to the strong affinity between them, the myosin head binds to the actin (crossbridge).

viii) Crossbridge formation stimulates ATPase activity, and allows the power stroke to occur. The power stroke is the 'pulling' of actin toward the M line by the pivoting of the myosin head. The myosin head is going from a high E state to a low E state during the power stroke (PE converted to KE).

ix) If more ATP is available, then the cross bridge is broken and myosin releases actin. This allows for the repositioning of the myosin head into the high energy state.

x) Then, if the nerve impulse is still present, steps 7 through 9 will be repeated.

xi) This muscle contraction will continue until:

a. The impulse stops or

b. Fatigue occurs.

Locomotion in a finned fish

Locomotion in finned fish is by swimming. In this sub-unit, we will learn how locomotion occurs in a finned fish e.g. tilapia.

Activity 7.7: To observe and identify external features of a finned fish

Work in groups

Materials

- Tilapia fish or any other available finned fish
- Dissection board or plate
- Scalpel

Procedure

Precaution: Handle the fish carefully because the spines are sharp and can prick you.

1. Hold the fish in your hands. Is its body flexible and able to bend or is it stiff?
2. How does the flexibility of the region near the head compare with that of the tail region?
3. Hold the fish with head pointed towards you as if the fish was moving towards you.
4. Describe the shape of the body of the fish.
5. Place the fish on a dissecting board.

6. Pass your hand carefully from the head to the tail end and back again to the head region. How do you feel? How are the scales arranged? What is the importance of this arrangement of scales?
7. Look at the fins. Try to gently spread out the fins. What do you note? Note the position of each of the fins on the body of the fish. Note the fins that are paired and those that are not paired.
8. Locate the operculum. What do you think is its function?
9. Examine the eyes of the fish. Is there an eyelid to cover the eye? Why is this important in fish? Explain.
10. Locate a line of pores along the side of the fish. What is the name of the line and what is its function?
11. Measure the length of the tail from the anus to the end of the tail fin. Measure the length of the body of the fish from the mouth end to the end of the tail fin. Calculate the proportion of the tail length to the body length. This proportion gives the tail power and it is calculated as follows:

$$\frac{\text{Tail power}}{\text{Body length}} = \text{Tail length}$$

The higher the tail power, the greater the propelling force that push the fish forward.
12. Draw and label the external structure of the fish.

Study questions

1. Which end of the body of the fish is most flexible?
2. Describe the shape of the fish.
3. Describe the feel of the fish when you stroke it from the head to the tail.
4. What causes the feel?
5. How are scales arranged on the body of the fish?
6. How many fins does the fish have? How many are paired and how many are unpaired?
7. Give the position of the fins on the body of the fish.
8. How is fish adapted to its environment?

Adaptations for living in water

i) All fish have a streamlined body which reduces water resistance as the fish moves.

ii) They possess gills which enable them carry out gaseous exchange.

iii) Their body surfaces are smooth, covered with slime, which enables the fish to escape from the enemy in the water easily.

iv) Most fish have scales which protect the fish from external abrasion e.g. moving sticks in the water. These scales point backwards so as to reduce water resistance to a minimum. Those without scales have tough leathery skins for the purpose of protection.

v) Fish possess fins which are for balancing and motion in the water.

vi) Many fish possess a swim bladder, which is a gas-filled structure that enables them to alter their densities according to the depth of the water where they are. Hence, the swim bladder enables the fish to gain buoyancy at any depth.

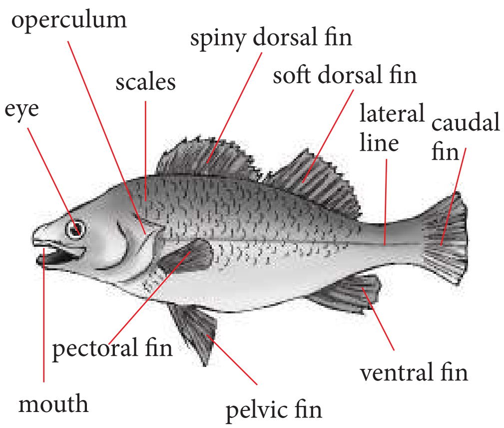


Fig 7.19: External parts of a fish (tilapia)

Locomotion of fish in water

The propulsive force that drives the fish through water comes from blocks of muscles found on either side of the back bone and around the fish.

- These blocks of muscles are in a zig zag pattern, one behind the other.
- When a fish is swimming, muscle blocks contract and relax alternately on each side of the back bone.
- The contraction and relaxation always begins from the head and continues to the end at the tail. These alternating contractions and relaxations bend the backbone into a continuous series of waves which move rapidly down the fish's length.

  At the end of the body is the tail fin.
- The side to side movements of this correspond to the muscle contractions. When the blocks of muscle on the left side contract, the tail fin swings to the left.
- When the ones on the right contract, it is pulled back to the right. As the tail pushes backwards on the water, there is a forward force created and so the fish moves forward.

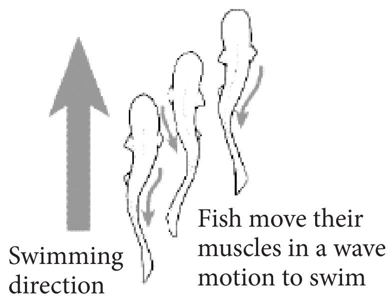


Fig 7.20: Locomotion of fish in water

Balance in fish

Fish face three types of instability in water.

i) **Pitching:** This is the forced up and down movement of fish. This is prevented by the paired fins. (pelvic and pectoral)

ii) **Yawing:** This is the side to side swaying of the fish from a straight course.

iii) **Rolling:** This is the turning over movement: Both (ii) and (iii) above are prevented by the action of the median fins (dorsal and ventral).

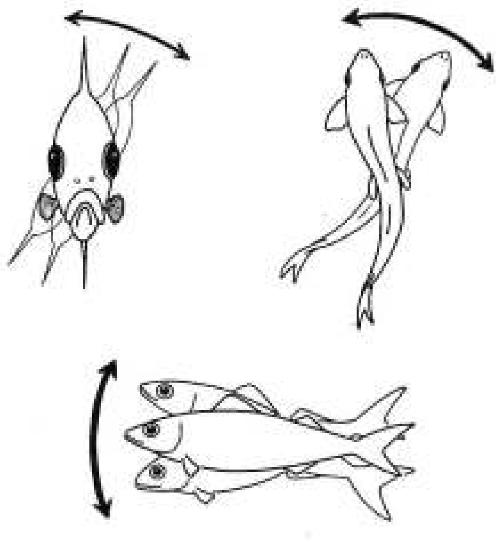


Fig 7.21: Balance of fish

Other functions of the paired fins

i) They are used for upward and downward movements in the water.

ii) Pectoral fins are used as breaks to stop forward movement.

iii) One pectoral fin can be used to act as a pivot so that the fish can make a sharp turn.

Locomotion in birds

Activity 7.8

Work as a class

Watch a video clip from the following link: https://www.youtube.com/watch?v=YhWbKvR_GBA

Study questions

1. How are the bones of birds adapted for locomotion in air?
2. Name the two muscles in birds that play a vital role in bird's flight.
3. Why do most birds move in a team when flying for long distances? Explain.
4. Give other adaptations of a bird's body that enable it to fly from one place to another.

Locomotion is brought about by contraction of muscles in most of the vertebrates.

- The normal way of movement is walking but birds and bats are unique animals in that they have the ability to fly.
- A few birds are completely unable to fly, e.g. ostriches, emus, kiwis, etc. These have evolved long legs suitable for running and happen to be fast runners.
- The ability to walk also varies from species to species and this depends upon the habitats in which the animals are found. Some good fliers, e.g. the European swift, have almost lost the ability to walk. Some aboreal ones, e.g. the terokos, walk by hopping method which is good for their type of life.

Adaptations of the birds for flight

i) Fore limbs have been modified to form wings for flapping.

ii) Wings provide a large surface area for movement in air.

iii) Presence of large pectoral muscles, the pectoralis major and pectoralis minor, which flap the wings when they contract.

iv) A light and strong skeleton made up of hollow and small bones which can be easily moved in the air.

v) A rigid skeleton made up of fused bones with a deep keel like extension of the sternum which provides a large surface area for the attachment of muscles.

vi) An efficient breathing system with air sacs attached to the lungs necessary to provide the necessary oxygen for respiration and to removing the resulting carbon dioxide.

vii) A high metabolic rate for providing the high amount of energy required for flight

viii) An efficient circulatory system necessary for transporting both the nutrients and respiratory gases as fast as the body needs require.

ix) A high red blood cell count for efficient oxygen transport.

x) A keen eyesight to enable them to judge distances correctly especially on quick landing.

xi) A stream lined shape to reduce air resistance and provide smooth movement in the air.

xii) Ability to fold the leg away during flight so as not to cause any unnecessary friction with the air.

xiii) Possession of feathers for beating the air. Also feathers insulate the body against heat loss during the flight.

xiv) Feathers are light to reduce the body weight.

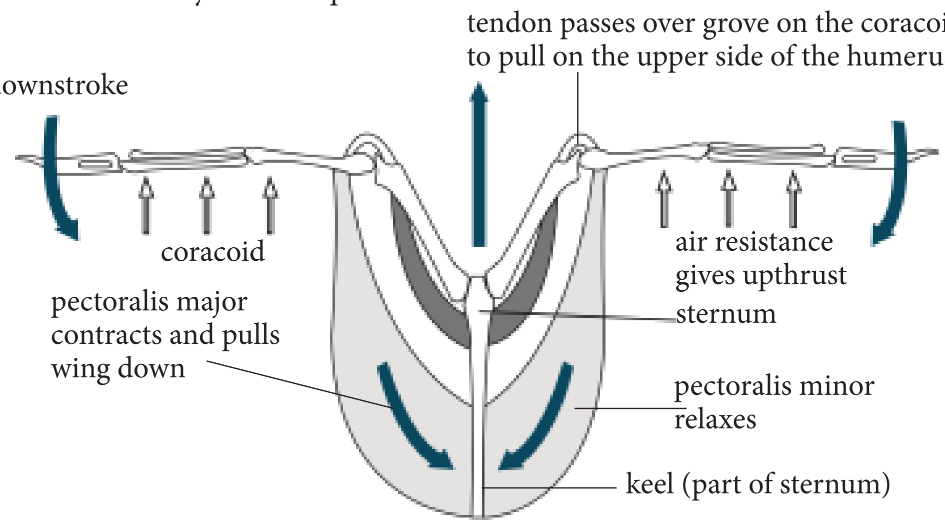


Fig 7.22: Pectoralis minor: Contracted, short and fatter

The structure of a bird's wing

Wings perform two main functions.

(i) They provide support for the bird in air.

(ii) They propel the bird forward during flight.

The quill feathers fixed to the posterior border of the wing are called the primaries. Those at the anterior border are called secondaries. The bases of the quill feathers are covered by small feathers called wing coverts which prevent air from passing through the bases. A bird's wing is shaped like an arch, i.e. it is rounded on top and hollowed underneath. Therefore, a bird's wing is said to be shaped like an aerofoil.

Flight in birds

There are two main types of flight in birds.

(i) Flapping flight

(ii) Soaring and gliding flight

Flapping flight

This is also called **active flight** because the bird uses energy. The wings are moved (flapped) up and down.

- The upward movement of the wing is called the **upstroke**.
- The down ward movement of the wing is called the **down stroke**.

  These two movements are brought about by the action of the powerful breast muscles. These muscles are of two types:

  i) The depressor muscle (pectoralis major) which causes the down stroke by pulling the wings downwards.

  ii) The elevator muscle (pectoralis minor) which causes the up stroke by pulling the wing upwards.

Structure and functions of feathers

There are four types of feathers.

i) Quill feathers

ii) Covert feathers

iii) Down feathers

iv) Filoplumes

On the body, feathers are arranged in rows.

> **Activity 7.9**
>
> Work in groups.
>
> 1. Obtain feathers of different birds such as hen, duck, peacock.
> 2. Observe how the feathers look like. Are they the same?
> 3. What are some of the differences you can observe?
> 4. Why do you think the feathers are not the same? Explain.
> 5. What do you think are the functions of different types of feathers in a bird?

Quill feathers structure

A typical quill feather has the stiff shaft that supports the vane and resists breakage due to air pressure. The long quill is hollow with a hole at the base called inferior umbilicus and another hole known as superior umbilicus. The quill is hollow to reduce weight during flight. The quill is also long for attachment of the feather into the skin. The shaft has tiny branches called barbs arranged obliquely on either side. Each barb bears two rows of small branches called barbules. Some barbules have hooks while others have ridges. Those with hooks are opposite those with ridges and the result is that they interlock with those that have ridges. This binds the whole vane together so that it can beat the air. All the barbules in the vane of a quill feather are interlocked to make smooth vane that resists air pressure during flight. The vane is large to provide a large surface area for resisting the air during flight.

Down feathers They are small soft feathers that cover and insulate the whole body of a bird. They are the only feathers in a bird's nestling. In adults, they lie between and beneath the contour feathers. Down feathers have a fluffy appearance as their barbs are not joined together to form a smooth vane.

Fig 7.23: Down feathers

Covert feathers mostly cover other feathers in a bird. It plays an important role in enhancing smooth airflow over the wings and tail of a bird. Covert feathers can be found at the ears, wings or tail in birds.

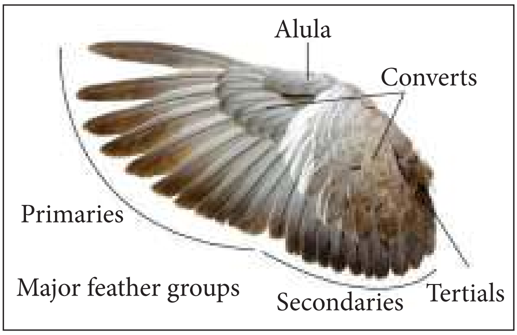


Fig 7.24: Covert feather

Filoplumes consist of a long, slender rachis that is often soft and has very few barbs at the distal end. They are usually hidden by the contour feathers, but in some birds such as cormorants, they emerge to the surface at the neck and back of the head.

Fig 7.25: Filoplume

The skeletal system

Skeletal system consists of a framework of bones and a few cartilages. This system has a significant role in movement shown by the body. Imagine chewing food without jaw bones and walking around without the limb bones. Bone and cartilage are specialised connective tissues.

The facts

The types of skeleton

Skeleton supports the body, gives rigidity to the body, provides surface for attachment of muscles and protects soft internal organs like the brain, heart, lungs etc.

Skeletal system is made up of:

- bones
- cartilage
- tendons
- ligaments

There are three types of skeletons, i.e

a) Hydrostatic skeleton
b) Exoskeleton
c) Endoskeleton

The facts

Hydrostatic skeleton

This type of skeleton is provided by a fluid-filled cavity under pressure. The pressure enables the body to maintain its shape. This skeleton provides the major support in most invertebrates like earthworms, sea anemones, leeches etc. Similarly, in unicellular organisms and other cells, the support system is provided by hydrostatic skeleton, in which case it is known as cytoskeleton. In the earthworm, movement is brought about when muscles attached to the skin move against this fluid which is turgid enough to support them.

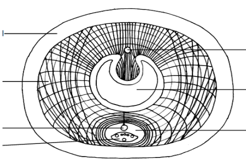


Fig 7.26: Muscle fibre arrangement in an intersegmental septum in Lumbricus terrestris

Types and functions of skeletons

Two main types skeletons are exoskeleton and endoskeleton.

Activity 7.10: To examine the exoskeleton in arthropods

Work in groups

Materials

- Pair of forceps
- Preserved crab
- Beetle
- Hand lens
- Cockroach
- Grasshopper
- Sharp knife
- Earthworm

Procedure

1. Observe the external structure of the exoskeleton of the specimen provided.
2. Observe the movement of the earthworm.
3. Hold the specimen (earthworm) with a pair of forceps while using a hand lens.
4. Note the firmness and the rigidity of the exoskeleton.
5. Hold a limb and try to bend it gently at its joint. What do you observe?
6. Draw a well labelled diagram of each specimen and label it. Use a different colour to show the exoskeleton.

Study questions

(i) What was the feel of the exoskeleton when you touched it?
(ii) Is the exoskeleton one continuous structure or is it in parts?
(iii) Where were the muscles attached to the exoskeleton?
(iv) What do you think is the importance of an exoskeleton in arthropods? Explain.
(v) Explain how the internal fluid in the earthworm causes movement.

Exoskeleton in arthropods

The prefix 'exo' from the word 'exoskeleton' means 'outside.'

An exoskeleton is therefore a skeleton found outside of the body of some animals.

- It is a hard outer covering of arthropods made up of mainly chitin. Chitin is a strong material and is light in weight. It is secreted by epidermal cells and hardens on secretion.
- It is strengthened by addition of other substances e.g. tannins and proteins to become hard and rigid.
- On the joints such as those in the legs, the exoskeleton is thin and flexible to allow for movement.
- It is found in animals such as crabs, spiders, locusts, millipids, bees etc.

Functions of exoskeleton

- Provide support.
- Attachment of muscles for movement.
- Protection of delicate organs and tissues.
- Prevention of water loss.

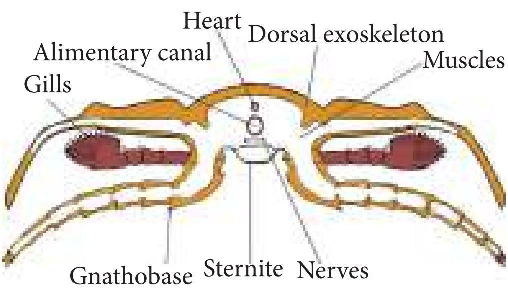


Fig 7.27: A cross-section of an insect showing an exoskeleton

Endoskeletons in vertebrates

The prefix endo in the word endoskeleton means inside.

An endoskeleton is therefore a skeleton found inside the body of a vertebrate. It is usually surrounded by muscles. The endoskeleton is made of bones and cartilage. The endoskeleton is made of living tissues and it can grow as the rest of the parts of the body grows.

a) It forms an internal body framework.

b) This is a type of skeleton characteristic of all vertebrates.

c) The endoskeleton is made of cartilage, bone or both.

d) It is made up of living tissues and grows steadily as animals grow.

e) Muscles are attached on the skeleton.

f) The muscles are connected to bones by ligaments.

Functions

i) The functions of endoskeleton include support, protection and movement.

ii) Locomotion in a finned fish e.g. tilapia.

iii) Most of the fishes are streamlined and have backward directed fins to reduce resistance due to water.

iv) It protects parts of the ear and eye.

v) It provides a surface for the attachment of the muscles.

vi) It works together with muscles to produce movement (movement of the whole body is known as locomotion).

vii) The framework of the skeleton gives the body its shape

viii) It is important in the formation of blood cells. Red blood cells are formed in the bone marrow of short and long bones.

ix) Skeleton also stores calcium and phosphorus.

Support system of land vertebrates

Vertebrate skeleton

In the vertebrates, skeleton is made of **bone** and **cartilage**. It is located inside the body and therefore referred as an endoskeleton.

a) Land vertebrates are supported by endoskeletons (internal skeletons).

b) The endoskeleton of land vertebrates is divided into two group:
   - i) axial skeleton (skull, rib cage and back bone)
   - ii) Appendicular skeleton (pectoral girdles, upper limbs and pelvic girdles, lower limbs)

c) The skeletal systems of land vertebrates:
   - i) give them structure, strength and shape
   - ii) supports their weight
   - iii) protects their soft tissues and organs.

d) The weight of land vertebrates is supported mainly by the pectoral (shoulder) and pelvic (hip) girdles.

e) Birds have endoskeletons adapted for flight. Their endoskeletons are made up of lighter hollow bones and their forelimbs are modified to form wings.

Activity 7.11

Draw a mammalian skeleton.

On the skeleton, locate:

1. Axial skeleton
2. Appendicular skeleton
3. Locate the rib cage, the skull and the girdles.
4. What are the functions of each part?

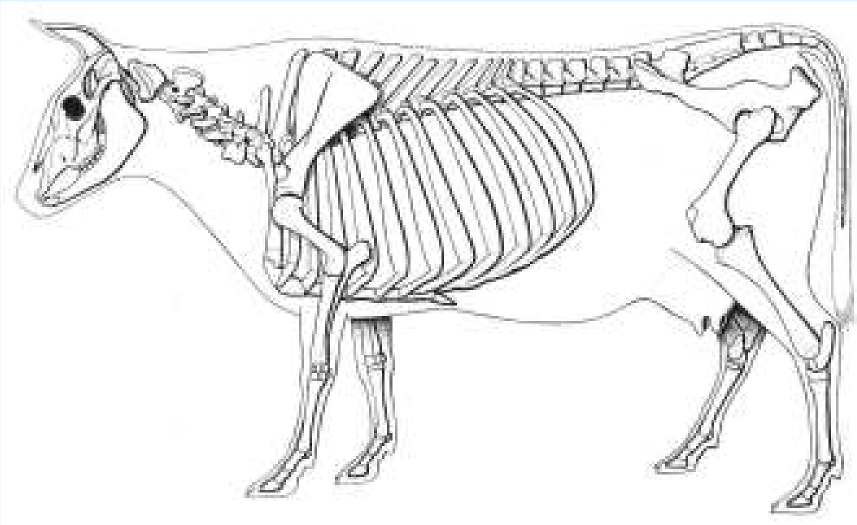
7.4 Mammalian skeleton

The mammalian skeleton is divided into two: Axial and appendicular.

- Axial skeleton is made up of the skull and the vertebral column.
- Appendicular skeleton is made up of the pelvic and pectoral girdles and limbs (hind limb and forelimbs).

Activity 7.12:

Draw the diagram of a mammalian skeleton.



The axial skeleton

This consists of the:

i) Skull
ii) Sternum
iii) Ribs
iv) Vertebral column

The skull

Activity 7.13: Examining the structure of the skull

Materials

- Skull of a mammal e.g. cow, sheep or goat
- Hand lens

Procedure

1. Observe the specimen provided carefully.
2. Identify the following parts:
    - Sutures
    - Opening of the nose and ears
    - Occipital condyle
    - Orbits
    - Foramen magnum
    - Cavity that holds brain
3. Draw a well labelled diagram of the skull and label the parts.
4. Compare the drawn structure with the human skull.

i) The skull is made up of cranium and facial bones.
ii) The cranium encloses and protects the brain.
iii) It is made up of many bones joined together by immovable joints.
iv) The facial bones consist of the upper and lower jaws.
v) At the posterior end of the cranium are two smooth rounded protuberances, the occipital condyles.
vi) These condyles articulate with the atlas vertebra to form a hinge joint, which permits the nodding of the head.

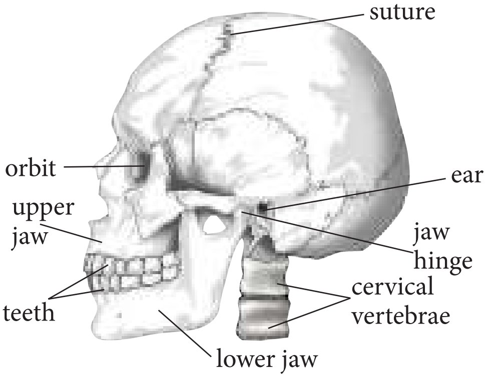


Fig. 7.28: Human skull.

Sternum and ribs

i) They form the rib-cage.

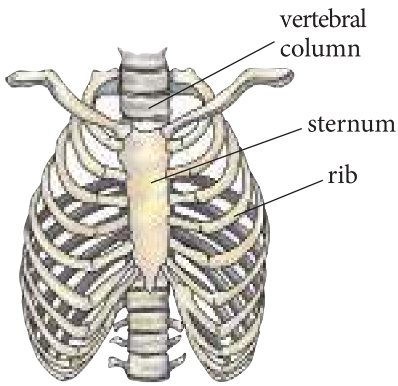


Fig. 7.29: Ribcage

ii) The rib-cage encloses the thoracic cavity protecting delicate organs such as the heart and lungs.

iii) The ribs articulate with the vertebral column at the back and the sternum at the front.

The vertebral column

Activity 7.14: Examining bones of the vertebral column

Work in groups.

Materials

- Various bones of the vertebral column
- Hand lens
- Pictures and photographs of the bones found in the vertebral column.

Procedure

1. Examine the specimens provided using a hand lens.
2. Look at the pictures and photographs provided.
3. Investigate your own skeleton and relate them to the pictures and specimen you examined.
4. Make a drawing of the features seen and label the various parts.

The facts

i) The vertebral column is made up of bones called **vertebrae** placed end to end.

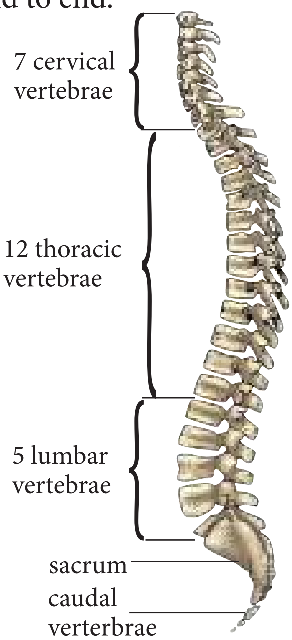


Fig 7.30 Vertebral and discs column

ii) The vertebrae articulate with one another at the articulating facets.

iii) In between one vertebra and another is the cartilaginous material called intervertebal disc.

iv) The discs act as shock absorbers and allow for slight movement.

v) Each vertebra consists of a centrum and a neural arch which projects into a neural spine.

vi) The neural canal is the cavity enclosed by the centrum and the neural arch.

vii) The spinal cord is located inside the canal.

The neural spine and other projections e.g. transverse processes serve as points of attachment of muscles.

Table 7.4: Type and number of vertebrae in a human and rabbit

	Vertebrae	Human	Rabbit
1.	Cervical (neck)	7	7
2.	Thoracic (thorax)	12	12
3.	Lumbar (upper Abdomen)	5	7
4.	Sacral (lower abdomen)	5	3-4
5.	Caudal	4 (coccyx)	16

Cervical vertebrae

i) These are found in the neck region of a mammal.

ii) The distinguishing feature is a pair of verte-braterial canals in the neural arch, through which the blood vessels of the neck pass.

iii) Another feature is the structure of the transverse processes.

iv) They are flattened out and are known as cervical ribs.

v) The first cervical vertebra is known as the atlas.

vi) It has a large neural canal and no centrum.

vii) The second cervical vertebra is called axis.

viii) The other five cervical vertebrae have no specific names.

ix) They have the same structure.

x) The cervical vertebrae possess numerous processes for muscle attachment.

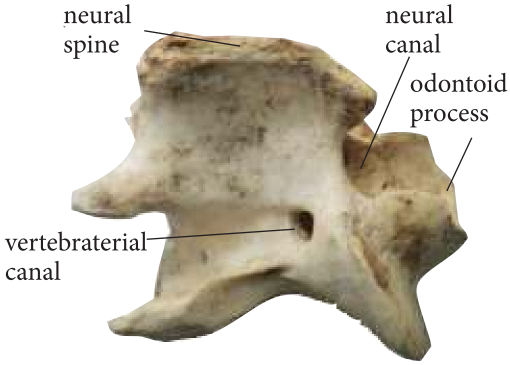


Fig. 7.31: Cervical vertebrae (side view)

Thoracic vertebrae

- Each thoracic vertebra has a large centrum, a large neural canal, neural arch and a long neural spine that projects upwards and backward.

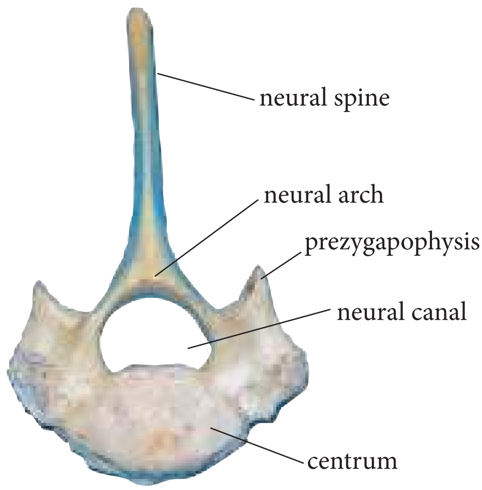


Fig. 7.32: Thoracic vertebrae

- There is a pair of prezygapophyses and postzygapophyses for articulation with other vertebra.
- They have a pair of short transverse process.
- The thoracic vertebra also articulates with a pair of ribs at tubercular and capitular facets.
- The **thoracic vertebrae** together with the **ribs** and sternum form the **thoracic cavity**. The main role of the thoracic cage is to protect the heart, lungs and the major blood vessels against mechanical injury. It also plays a major role in breathing movements.

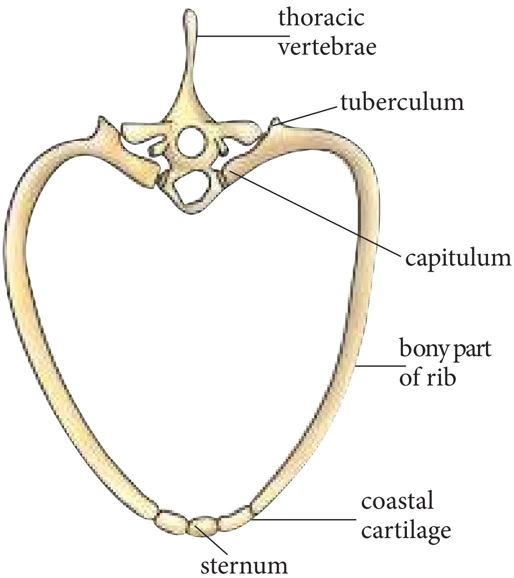


Fig. 7.33: Thoracic cavity

Lumbar vertebrae

i) Each lumbar vertebra has a large, thick centrum for support of the body.

ii) It has a neural spine that projects upwards and forwards.

iii) There is a pair of large transverse processes that are directed forward.

iv) Above the prezygapophyses lies a pair of processes called metapophyses.

v) Below postzygapophyses lies the anapophyses.

vi) Metapophyses and anapophysis serve for attachment of muscles of the abdomen.

vii) In some mammals, there may be another process on the lower side of centrum called hypapophysis also for muscle attachment.

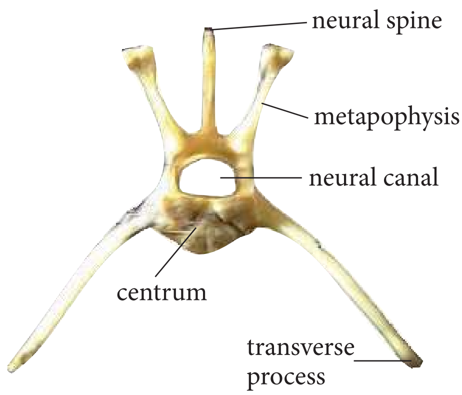


Fig 7.34: Lumbar vertebrae

Sacral vertebrae

i) The sacral vertebrae are fused together to form a rigid bony structure, the sacrum.

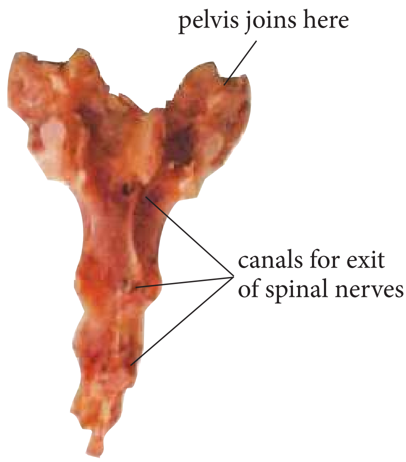


Fig. 7.35: Sacrum

ii) The centrum of each vertebra is large, but the neural canal is narrow.

iii) The neural spine is reduced to a small notch.

iv) The transverse processes of the first sacral vertebra are large and wing-like.

v) They are firmly attached to the upper part of the pelvic girdle.

Caudal vertebrae

- Human beings have only four of these vertebrae which are fused together to form coccyx.
- Animals with long tails have many caudal vertebrae.
- A typical caudal vertebra appears as a solid rectangular mass of bone.
- The entire bone consists of the centrum only.

Appendicular skeleton

- The appendicular skeleton consist of the limbs and their girdles.

Bones of fore limbs

Activity 7.15 Examining bones of the forelimb

Work in groups

Requirements

- Charts of humerus, radius and ulna
- Models or specimens of humerus, radius and ulna.

Procedure 1 (Humerus)

1. Examine the humerus carefully. Note the general shape.
2. Examine the two ends of the humerus.
3. Note the part of the bone between the two ends of the humerus.
4. Feel your own joints more and relate the structure to its function.
5. Draw and label the bone.

Procedure 2 (Ulna and radius)

1. Examine the ulna.
   - Note the depression that forms near one end of the ulna.
   - Note the section of the bone between the notch and the end of ulna.
   - Note that the shaft of the ulna curves slightly.
2. Examine the radius.
3. Compare the length of the radius with that of the ulna.
   - Note that the shaft of the radius is also curved.
4. Investigate the location of ulna and radius in your body and relate their structure to their function.
5. Draw and label the bones.

Study questions

1. Describe the length and shape of the humerus.
2. How does the length of the ulna compare to that of the radius?
3. Is the ulna and radius straight or curved?

Forelimbs are attached to the axial skeleton at the anterior part of the body.

Fig. 7.36: Skeleton of human forelimb

Pectoral girdle

- Pectoral girdle is made of scapula, coracoid and clavicle.

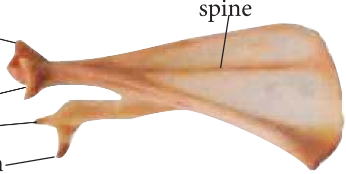


Fig. 7.37: Scapula

- A cavity known as glenoid cavity occurs at the apex of the scapula.
- The humerus of the forelimb fits into this cavity.
- The clavice is a curved bone connecting the scapular to the sternum.

Adaptations of scapula

- Scapula has glenoid cavity that provide a surface for articulation with the head of the humerus to allow movement of the arm.
- It has a broad and flattened surface to provide a large surface area for muscle attachment. It also has projections called **acromion** and **metacromion** to increase surface area for muscle attachment.
- Scapula has a long spine to provide large surface for muscle attachment. It is also bony to provide the strength required to sustain body weight.

Humerus

- Humerus is found in the upper arm.
- It articulates with the scapula at the glenoid cavity of the pectoral girdle and forms a ball and socket joint.

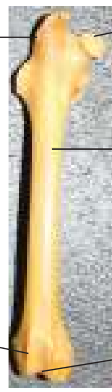


Fig. 7.38: Humerus

Adaptations of the humerus

- Humerus has a rounded head that fits into the glenoid cavity of the scapula to allow greater flexibility or movement of the arm.
- It is long to provide a large surface area for attachment of biceps and triceps muscles.

- It has trochlea at the lower end for articulation with forearm. This allows movement of the arm in one plane.

Ulna and radius

- These are two bones found in the forearm.
- The ulna has a projection called olecranon process and a sigmoid notch which articulates with the humerus.

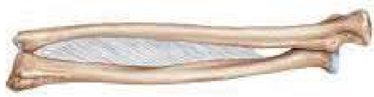


Fig. 7.39: Ulna and radius

Adaptations of the ulna and radius

- They are long to provide large surface area for attachment of the muscles of the forearm.
- Ulna has olecranon process with a **sigmoid notch** for articulation with trochlea of the humerus to allow movement in one plane. They are bony and strong to provide support.

Bones of hind limb

Activity 7.16: Examining bones of the hind limb

Requirements

- Labelled charts of femur, tibia and fibula.
- Models or specimens of femur, tibia and fibula.

Procedure

1. Examine the femur carefully. Note the general shape of the femur. Note that it is a single bone.
2. Examine the two ends of the femur. Note that at one end, there is a projection that forms a head. Note the three other processes at this end of the femur.
3. Examine the tibia and fibula closely. Notice that instead of two single bones, there are two bones that appear fused along half their length. Note that one is thinner than the other.
4. Investigate the position of a tibia and fibula in your body and relate their structure to their function.
5. Draw a well labelled diagram of femur, tibia and fibula.

Study question

1. Describe the length of the femur.
2. Describe the two ends of the femur.
3 Describe the relationship between the tibia and fibula.
4. Compare the size of the tibia to that of fibula.
5. What similarities and differences can you point out between femur and humerus? Explain your answer.

Hindlimbs are attached to the axial skeleton to the posterior part of the body.

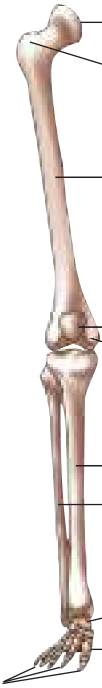


Fig. 7.40: Skeleton of human hindlimb

Pelvic girdle

- The pelvic girdle consists of two halves fused at the pubic symphysis.
- Each half is made up of three fused bones:
  - i) the ilium
  - ii) ischium
  - iii) pubis
- Each half has a cup-shaped cavity for the acetabulum for articulation with the head of the femur.
- Between the ischium and pubis is an opening, obturator foramen, where spinal nerves, blood vessels and a tough inflexible connective tissues pass.
- The ilium, ischium and pubis are fused to form the innominate bone.

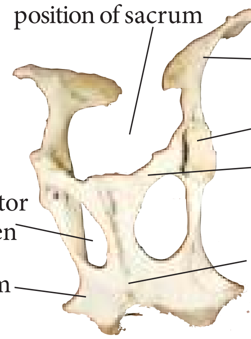


Fig. 7.41 Pelvic girdle

Adaptations of pelvic girdle

- The pelvic girdle is broad and flattened to provide large surface area for attachment of muscles.
- It is funnel-shaped to support the weight of the upper part of the body.
- It has grooves that provide surface for articulation with the head of femur bones to allow movement in all planes.

The femur

- The femur is the long bone joining the pelvic girdle and the knee.
- The head of the femur articulates with acetabulum forming the ball and socket joint at the hip.
- The femur has a long shaft.
- At the distal end it has condyles that articulate with the tibia to form a hinge joint at the knee.
- The patella covers the knee joint and prevents the upward movement of the lower leg.

Fig. 7.42: Femur

Adaptations of the femur

- It is long to provide a large surface area for attachment of thigh muscles. It is a bony shaft to offer support.
- It has a rounded head that articulates with acetabulum of pelvic girdle to allow flexible movement of the leg.
- It also has condyles for articulation with **patella** to allow movement in one plane at the knee.

Tibia and fibula

- The tibia is a large bone, and the fibula a smaller bone fused to it on the distal part.
- In humans, the tibia and fibula are clearly distinguishable.

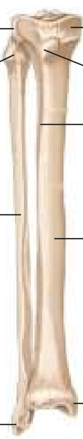


Fig. 7.43: Tibia and fibula

Adaptations of tibia and fibula

- They are long bones to provide large surface area for attachment of leg muscles.
- They are also bony and strong to provide support for body weight.

Joints and movement

Activity 7.17 Investigating how joints work

Work in pairs.

1. Ask your partner to try moving his arm in a clockwise manner. What happens?
2. Ask him or her to straighten and fold his or her fingers. What do you see?
3. Let your patner try to stretch or bend his arm three times. What makes the hand straighten and bend?
4. Now role-play stretching and bending the knee. What do you see?
5. What do you think makes the knee to stretch and bend? Explain.

The facts

- A joint is a connection between two or more bones.
- Joints provide articulation between bones, making movement possible.
- However, some joints do not allow any movement, e.g. the joints between bones of the skull.
- Movable joints are of three main types:

Gliding joint

- Joints which occur between the vertebrae wrists and ankles.
- The ends of the bones that make the joint are covered with cartilage.
- The bones are held together by tough ligaments.

Synovial joint

- The joint is enclosed by a fibrous capsule lined by synovial membrane which secretes synovial fluid into the synovial cavity.
- The synovial fluid lubricates the joint.
- They are called synovial joints.
- They include the hinge joint and ball and socket joint.

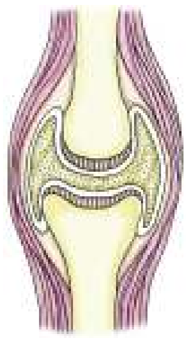


Fig. 7.44: Synovial joint

Hinge joint

- An example is the knee joint.
- The joint allows movement in one plane.

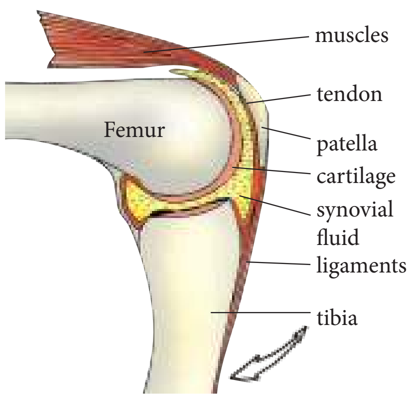


Fig. 7.45: Hinge joint of the knee

Activity 7.18

Take time to inspect your classroom door.

i) What holds the door onto the frame?
ii) Can the door move i.e. open and close?
iii) Ask your friend to open and close the door as you watch

Notice too that the door is held in place by hinges that allow this movement

Ball and socket joint

- Examples are hip and shoulder joints.

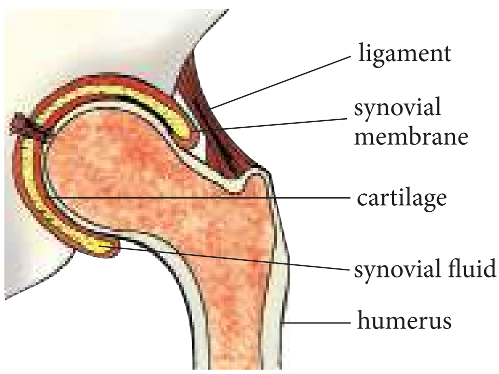


Fig. 7.46: Shoulder joint

- The joint allows rotation in all directions.

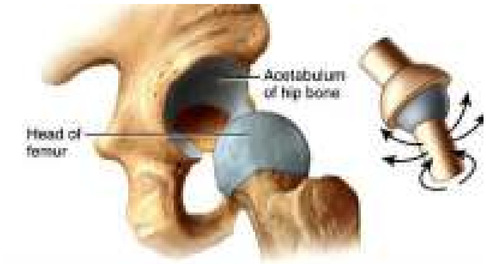


Fig. 7.47:

Types, locations and function of muscles

- There are three types of muscles, located at various parts of the body.
- In order to function all use energy in form of ATP.
- These include **smooth**, **skeletal** and **cardiac muscles**.

Smooth muscle (involuntary muscles)

- These are spindle-shaped and contain filaments with myofibrils.
- Each muscle is bound by a plasma membrane.
- They are found lining internal organs such as the alimentary canal, bladder and blood vessels.
- They are controlled by the involuntary part of the nervous system.
- They are concerned with movement of materials along the organs and tubes.
- They contract slowly and fatigue slowly.

Skeletal muscle (striated or voluntary muscle)

- Skeletal muscles are **striated** and have several nuclei.
- They are long fires each containing myofibrils and many mitochondria.
- They have cross-striations or stripes.
- They are also called **voluntary muscles** because their contraction is controlled by voluntary nervous system.
- They are surrounded by connective tissue and are attached to bones by tendons.
- Their contraction brings about movement of bone, resulting in locomotion.
- They contract quickly and fatigue quickly.

Cardiac muscle

- Consist of a network of striated muscle fibres connected by bridges.

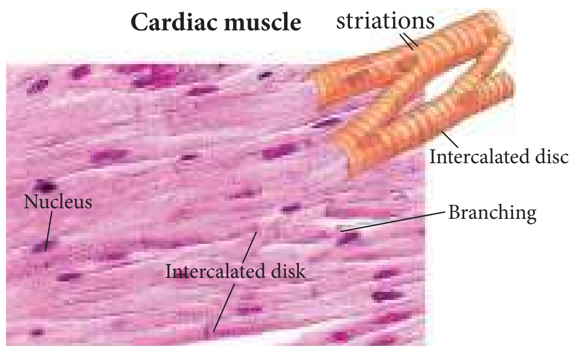


Fig. 7.48:

- Are short cells with numerous mitochondria and uninucleate.
- They are found exclusively in the heart.
- Contractions of cardiac muscles are generated from within the muscles and are rhythmic and continuous hence they are myogenic.

- They do not tire or fatigue.
- The rate can be modified by involuntary nervous system.
- Their contractions result in the heart pumping blood.

Role of muscles in movement of the human arm

- Muscles that bring about movement are antagonistic i.e. when one set contracts the other relaxes.

Antagonistic muscles of human forelimb

- The bicep muscles of the forelimb act as flexors while the tricep muscles act as extensors.
- The biceps has its point of origin on the scapula and the point of insertion on the radius.
- The triceps has its points of origin on the scapula and humerus and is inserted on the ulna.
- When the muscles contract, the limb acts as a lever with the pivot at the joint.
- Contraction of bicep muscles bends (flexes) the arm while contractions of triceps extends the arm.

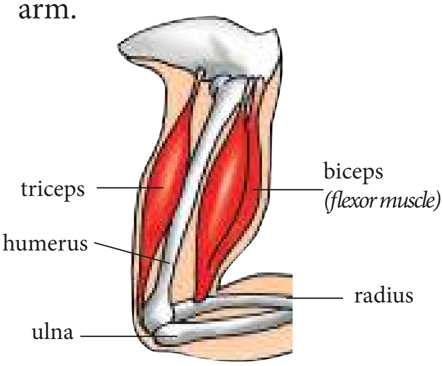


Fig. 7.49: Bending the arm

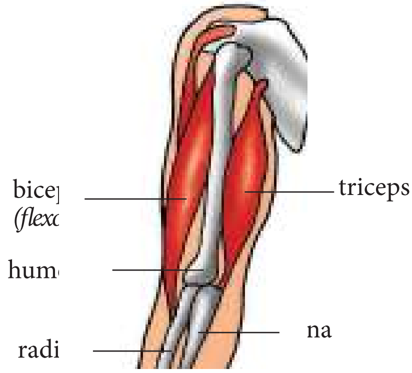


Fig. 7.50: Straightening the arm

Muscular and skeletal disorders

You have all seen some people who are wheel-chair bound. They are unable to move on their own. You have just learnt that muscle contracts only when stimulated by nerves.

If nerve supply to muscles get severed, muscles gradually weakens or atrophies.

The old may limp because of calcium deficiency or deficiency of Vitamin D3 which is responsible for calcium absorption.

Injury to limb or girdle bones also hampers locomotion. But these, apart some muscular and skeletal disorders, are hereditary e.g. myaesthenia gravis and muscular dystrophy. Arthritis and rheumatoid arthritis may or may not be hereditary. Osteoporosis and gout are due to nutritional deficiency and metabolic errors. Let us learn a little about them.

Myaesthenia gravis is because of a gene on X chromosome and so is hereditary. The muscles slowly waste away and the patient gradually becomes immobile and in the last stages, even the jaw muscles do not work and the patient is unable to eat.

Muscular dystrophy is an autosomal dominant disorder. In this hereditary disorder, muscles waste away and the person becomes immobile.

Arthritis and Rheumatoid arthritis are disorders of bones, especially, joints. There is constant joint pain in Rheumatoid arthritis, which is a crippling disease. Hands and feet become crooked due to inflammation in the joints.

Osteoporosis is the softening of bones due to calcium deficiency. You know that calcium absorption is dependent on availability of Vitamin D. So it is important to expose oneself to the sun every day for at least half an hour. You have already learnt that sunlight helps to generate Vitamin D. Post menopause ladies are prone to osteoporosis. This is because estrogen, the female hormone, mobilises calcium and sends it to bones. In the absence of estrogen, bones tend to crack and break.

Gout results in painful inflammation of joints due to elevated level of uric acid in blood. Uric acid is a product of protein metabolism. Gout can be cured.

Check your progress 7.3

1. What do the terms axial and appendicular mean?
2. Name components of axial skeleton.
3. Name the components of appendicular skeleton.

Glossary

Achene: A simple, dry one-seeded indehiscent fruit with the seed attached to the ovary wall at one point only. e.g. strawberry, sunflower

Anemophilus: Flowers that are pollinated by wind.

Antenna (plural: antennae): A moveable sense organ found on the heads of many arthropods.

Antheridiophore: A stalk that carries the antheridia in liverworts.

Artificial breeding: Also known as selective breeding is a process in the breeding of animals and in the cultivation of plants by which the breeder chooses to perpetuate only those individuals having certain desirable inheritable characteristics.

Assimilation: The incorporation of organic and inorganic material into protoplasm.

Biotechnology: The exploitation of biological processes for industrial and other purposes, especially the genetic manipulation of microorganisms for the production of antibiotics and hormones.

Capitulum: Stalk less flowers arranged in the same plane at the expanded apex of the axis.

Capsule: A simple, dry, dehiscent fruit with two or more carpels.

Carapace: A chitinous structure covering the cephalothorax of many arthropods.

Carpel: Female reproductive organ of flowering plants. In some plants, one or more carpels unite to form the pistil.

Carpellate flower: A flower having carpels or pistils but not stamens.

Cell cycle: The stages through which a cell passes between one division and the next. It includes all stages of interphase and mitosis.

Centromere: Constricted region where sister chromatids are attached.

Cephalothorax: The body division comprising the united head and thorax of arachnids and higher crustaceans.

Chiasmata: The X-shaped figure formed by the meeting of two non-sister chromatids of homologous chromosomes during meiosis; the site of crossing-over where two chromatids have exchanged parts.

Chromatin: Substance found in cell nuclei that forms chromosomes during cell division.

Cloning: It's a form of asexual reproduction in which an organism can be reproduced from a single cell.

Coleorhizza: Sheath that surrounds the radicle of the grass embryo and through which the young developing root emerges.

Collenchyma: A simple plant tissue (one cell type only). It is often found in regions of primary growth, in stems that are lengthening and in some leaves, where it gives flexible support.

Companion cell: Living parenchyma cell that is specialised to help load organic compounds into adjacent conducting cells of phloem.

Cork: An external, secondary tissue impermeable to water and gases produced by certain kinds of woody plants.

Corpus luteum: The remains of a ruptured follicle in the ovary. It produces progesterone for a short period of time.

Cortex: Primary tissue of a stem or root bounded externally by the epidermis and internally in the stem by the phloem and in the root by the pericycle. It supports plant parts and stores food in stems and roots.

Corymb: As in the raceme but with the pedicels all of different lengths, the lowermost longest, so that the flowers are all brought to the same level.

Crenate: Notched with blunt or rounded teeth.

Cuneate: Of a leaf, wedge-shaped.

Cytokinesis: The division of the cytoplasm after nuclear division. The cell divides into two parts, each containing one of the newly formed nuclei and half of the other contents of the parent cell.

Cytokinin: Type of plant hormone that stimulates cell division, promotes leaf expansion and retards leaf aging.

Dehiscent fruit: A fruit that splits open at maturity of pods or capsules along definite lines.

Dentate: Prominently toothed and the teeth directed outwards.

Differentiation: Development from one cell to many cells, together with a modification of the new cells for the performance of particular function.

Dioecious: Having the male and female elements on different individuals.

Divergent evolution: Adaptation to different kinds of environment that results in divergence from a common ancestral form.

DNA(Deoxyribonucleic acid): is a molecule that carries most of the genetic instructions used in the development, functioning and reproduction of all living organisms.

Drupe: A simple, fleshy fruit derived from a single carpel, usually one-seeded, in which the epicarp is thin, the mesocarp fleshy, and the endocarp hard.

Effectors: These are structures that aid animals to react to stimuli i.e. they carry out a response. They can be glands or cells.

Endocrine glands: A ductless structure whose secretion e.g. hormone, is passed into adjacent tissue and then to the bloodstream.

Endometrium: A tissue supplied with blood vessels, which forms a lining of the uterus and is shed each month during menstruation.

Entomophilus: Flowers that are pollinated by insects.

Epicalyx: A ring of fused bracts below the calyx forming a structure that resembles the calyx.

Epicotyl: The upper portion of the embryo axis or seedling, above the cotyledons and below the first true leaves.

Exodermis: Cylindrical sheet of cells just inside the root epidermis of most flowering plants; helps control uptake of water and solutes.

Fertilisation: The fusion of male and female gamete to form a zygote.

First generation: Refers to the offspring that are produced after crossing the parental genotypes.

Follicle: A simple, dry dehiscent fruit, having one carpel and splitting along one suture.

Fossil record: The history of life as determined by the relative age of fossils.

Frond: The leaf of a fern.

Genetic engineering: It is a set of technologies used to change the genetic makeup of cells, including the transfer of genes within and across species boundaries to produce improved or novel organisms.

Genome: Refers to the total genetic constitution of any cell in an organism.

GMO: A genetically modified organism, or GMO, is an organism that has had its DNA altered or modified in some way through genetic engineering.

Ground meristem: Primary meristem that gives rise to the epidermis and vascular tissues.

Growth ring: A growth layer in the secondary xylem or secondary phloem as seen in transverse section.

Haploid: It's an organism or cell that comprises of a single set of chromosomes.

Hastate leaf: One with a horizontal base and sharp apex.

Haustorium: A special penetrative, food-absorbing structure formed within a living plant host cell at the end of the hyphal branch of certain parasitic fungi.

Herb: A non-woody plant, often dying after flowering.

Hypha (plural: hyphae): One of the filaments composing the mycelium of a fungus.

Imago: Sexually mature adult insect.

Imbibition: The absorption of water onto the internal surfaces of colloidal materials resulting in the swelling of organs, such as seeds during germination.

Inflorescence: Clusters of flowers formed on a modified shoot.

Instar: A stage between moults in the life of arthropods, especially insects.

Integument: Of seedbearing plants, one or more layers around an ovule. It becomes a seed coat or testa.

Internode: The region of a stem between two successive nodes.

Interspecific: Interaction involving different species.

Juvenile hormone (neotenin): A hormone secreted by the cell of the corpus allatum in arthropod larvae and nymphs with inhibits the development of adult characteristic.

Lanceolate leaf: A leaf in which the length is 3-6 times the breadth and the broadest part is below the middle part; it's also tapered gradually to the apex.

Leaf primordium (pl. primordia): A lateral outgrowth from the apical meristem that will eventually become a leaf.

Monoecious: Having male and female reproductive organs in the same individual.

Moulting (ecdysis): The shedding of an outer covering as part of a periodic process of growth.

Mucronate leaf apex: Apex at which the midrib is prolonged into a small point.

Multiple fruit: A cluster of matured fused ovaries produced by separate flowers e.g. pineapple.

Mycelium: A mass of filaments or hyphae composing the vegetative body of many fungi.

Myometrium: Middle uterine layer comprising of smooth muscles.

Nut: A dry, indehiscent, single-seeded fruit with a hard, woody epicarp (shell) e.g. peanut (ground nut).

Oblong: (of a leaf) With length about 2-6 times the breath, with sides more or less parallel, and a rounded apex.

Palmate: Used of a leaf whose leaflets radiate from the apex of the petiole like the outspread fingers of a hand.

Parenchyma: Simple tissue that makes up the bulk of a plant; has roles in photosynthesis, storage, secretion and other tasks.

Parietal ovules: Ovules that are located on the wall, as distinct from axile, apical or basal.

Parthenocarpy: Formation of fruits without fertilisation.

Pedicel: The stalk of a single or individual flower in an inflorescence.

Peltate: A leaf in which the lamina develops outwards on all sides of a centrally-placed petiole. This is really a cordate leaf with the two lobes united.

Perennating organ: Part of a plant that is adapted to sustaining an organism through adverse or unfavourable conditions and is capable of developing into one or more new plants.

Pome: A simple fleshy fruit, the outer portion of which is formed by floral parts that surround the ovary i.e. apple and pear fruits.

Primary growth: Growth originating in the apical meristems of shoots and roots. It results in an increase in length.

Primary tissues: Tissues that compose the primary plant body.

Procambium: In vascular plants, a primary meristematic tissue that gives rise to primary vascular tissues.

Protandry: The condition in which anthers mature before carpels.

Protogyny: Condition in which flowers (termed protogynous) whose carpels mature before their anthers, as in plantains.

Receptors: These are structure or organs that receive stimuli e.g. skin, eye, ears, tongue and nose. They are also known as sense organs.

Raceme: Individual stalked flowers arranged along a single undivided peduncle.

Rachis: The axis of an inflorescence or of a compound leaf.

Reflex arch: Described as the path taken by a nerve impulse in a reflex action.

Reniform leaf: Kidney-shaped leaf

Rhizoids: A root-like structure which helps fungi, liverworts, lichens, mosses and ferns to hold to a substrate.

Rhizome: In vascular plants, a usually more or less horizontal underground stem; may be enlarged for storage or may function in vegetative reproduction.

Rosette: A dense cluster of leaves resembling in arrangement of the petals of a double rose.

Sagittate leaf: A leaf that is arrow-shaped, i.e. with two acute basal lobes directed downwards.

Samara: A dry, indehiscent, simple fruit that has wing-like appendages on both sides of the ovary. The appendages help carry the wind-borne fruit.

Sclereid: In vascular plants, a sclerenchyma cell with a thick, lignified secondary wall having many pits; not elongate like a fibre.

Sclerenchyma: Simple plant tissue that supports mature plant parts and commonly protects seeds. Most of the cells have thick, lignin-impregnated walls.

Scutellum: The flattened cotyledon of a monocot embryo, such as a grass.

Sexual harassment: Sex discrimination that involves bullying and coercion.

Sexuality: How a person expresses themselves as a sexual being.

Sieve cell: In the phloem of vascular plants, a long, slender sieve element with relatively unspecialised sieve areas and with tapering end walls that lack sieve plates.

Soil salinity: The amount of soluble salts in a soil, expressed as parts per million, millimho/cm, or other convenient ratios.

Sorus (plural, sori): A cluster of sporangia on the lower surface of a fertile fern leaf.

Spatulate leaf: A leaf that is spoon-shaped, broadly rounded above and tapering to the base.

Spike: Individual, unstalked (sessile) flowers, arranged along a single undivided peduncle: the common stalk of a cluster of flowers or the stalk of an inflorescence consisting of only one flower.

Spindle: A structure composed of fibres which converges toward opposite ends of the cell, but which appears during mitosis and meiosis. It carries out the separation of chromosomes during cell division

Stele: Cylinder or core of vascular tissue in centre of roots and stems, comprising xylem, phloem, pericycle, and in some steles, pith and medullary rays; surrounded by endodermis. Structure of the stele differs in different groups of plants.

Stipules: Leaf-like appendages that occur at the base of some flowering plant leaves or stems.

Suture: A line of junction, especially the line of opening of an anther.

Synapse: A specific functional point that links one neuron to another or it is a means by which a nervous impulse is passed from one neuron to another.

Synapsis: The pairing of replicated chromosomes during prophase I of meiosis. Crossing over takes place during synapsis.

Tetrad: A haploid cell formed from meiotic division of a pollen mother cell.

Truncate leaf apex: Terminating abruptly as if the end had been cut off in a straight line.

Umbel: Stalked flowers with the stalks of about the same length arising apparently from the same terminal point of the axis.