step ahead

Combined Science

FORM 3

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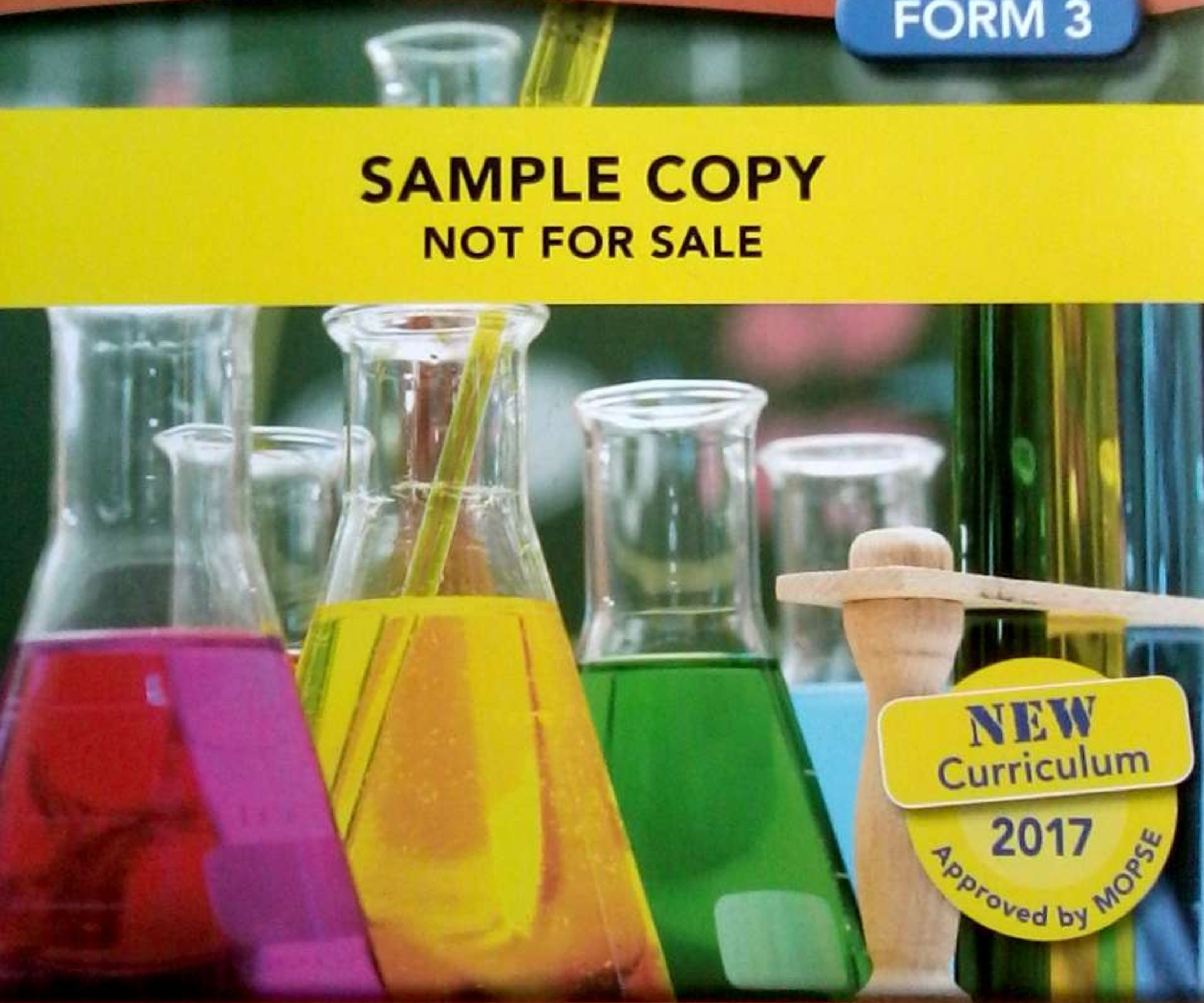


Learner's Book

Pearson

K Chavunduka

Contents

Topic 1: **Biology**

Unit 1 The structure and function of a cell

Objectives

- Identify specialised cells.
- Draw and label specialised cells.
- State the specific function or functions of specialised cells.
- Use a microscope to observe cell structures.

Introduction

Plants and animals are built up of small units called cells. Cells are the basic units of life. Cell **differentiation** takes place when a cell becomes specialised to perform a specific function. These cells change shape to become muscle cells, skin cells, root hairs, and so on. They now perform a specific function. Once specialised, these cells lose their ability to divide.

Specialised animal cells

Animals, like most plants, have many different cells that are specialised and carry out different functions. You are going to look at red blood cells and muscle cells as examples.

The structure and function of a red blood cell

Red blood cells are carried in the blood of animals. These cells carry oxygen from the lungs to all parts of the body.

Figure 1.1 Red blood cells carry oxygen.

Red blood cells look like round flat discs. They are thicker at the edges than in the middle. They are very flexible. This allows them to squeeze through thin blood vessels without breaking. They contain a red pigment called **haemoglobin,** which carries oxygen. Oxygen is needed for **cellular respiration** to produce energy in cells. You will learn more about this later.

The structure and function of a muscle cell

Muscles are made of strings of cells called muscle fibres. Skeletal muscle has long fibres held together in bundles. These muscles are attached to the skeleton to allow you to move around. Muscles contract to allow movement when stimulated by a nerve. Muscles pull on a bone to create movement.

Skeletal muscles are always arranged in pairs. When one muscle contracts, the other muscle relaxes.

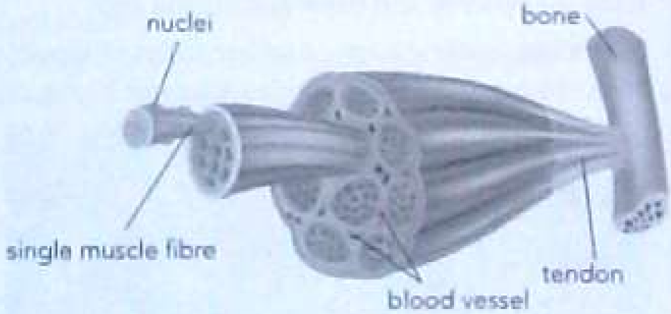


Figure 1.2 The structure of a muscle showing many muscle fibres

Specialised plant cells

Plants are multicellular organisms, made of many different types of cells. The cells perform different functions so that the plant can function as a unit. In the following section, palisade cells and root hair cells will be discussed.

The structure and function of a palisade cell

All leaves have a layer of palisade cells under the upper epidermis. The main function is **photosynthesis**. Palisade cells are long and shaped like cylinders. This allows them to be packed tightly next to each other to use space efficiently. The cell has a large surface area, which increases the area for **gaseous exchange**. The cell has a large **vacuole** to keep the cell rigid and support the whole leaf. The cell is packed with **chloroplasts** which contain the green pigment called **chlorophyll** to trap the Sun's energy for photosynthesis.

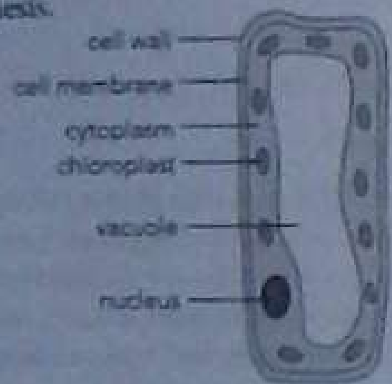


Figure 1.3 Structure of a palisade cell

The structure and function of root hairs

Root hairs are tiny cells found on the surface of plant roots. Their main function is to increase the root's surface area to absorb more water and minerals.

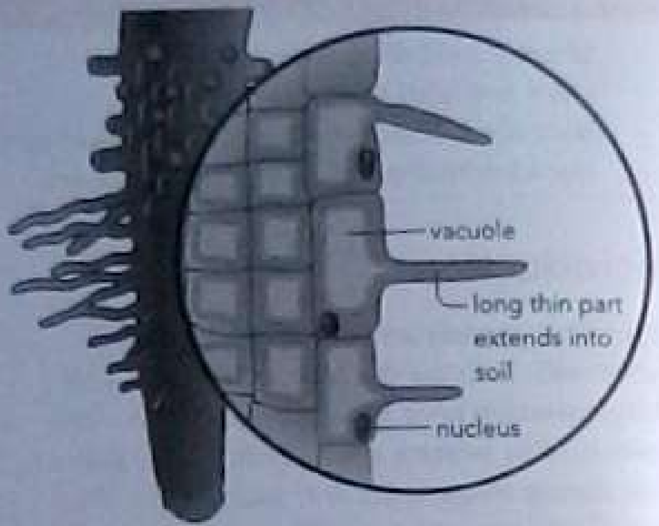


Figure 1.4 Root showing small root hairs

Root hair cells have long, thin parts that reach outwards into the soil. They increase the surface area of the root in contact with the soil. These cells have very thin cell walls to allow water and nutrients to pass from the soil into the root quickly.

Experiment 1.1

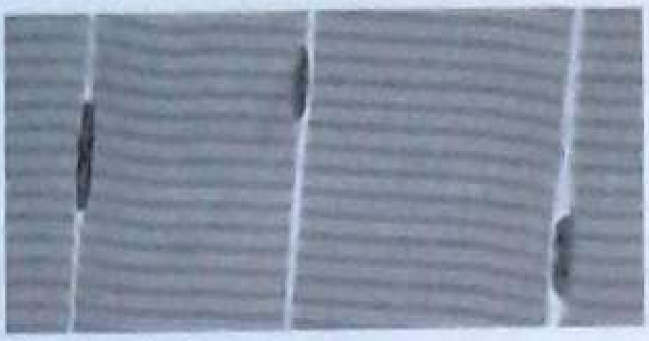
Aim: To observe and draw specialised cells

Materials: a microscope, biology slides of blood, muscle cells, palisade cells and root hair cells. In the event of prepared microscope slides not being available, use the diagrams below to do the activity.

Micrograph A

Micrograph B

Micrograph C



Micrograph D

Figure 1.5 Micrograph A, B, C and D

1. Identify the specialised cells shown in micrographs A to D.
2. Make a drawing of two or three cells from each micrograph.
3. Redraw the table below in your Workbook and complete the columns:

Cell	Function	Specialisation	Explain how each cell's specialisation helps it carry out its function
Red blood cells			
Muscle cells			
Root hair cells			
Palisade cells			

Summary

- Plants and animals are built up of small units called cells.
- Cells are the basic unit of life.
- Cell differentiation is when a cell becomes specialised to perform a specific function.
- Once specialised, these cells lose their ability to divide.
- All leaves have a layer of palisade cells under the upper epidermis.
- Their main function is photosynthesis so that the palisade cells are packed with chloroplasts.
- Palisade cells are like cylinders that have a large surface area to increase absorption of carbon dioxide and light for photosynthesis.
- A large vacuole keeps the cell rigid and supports the whole leaf.
- Root hairs are tiny cells found on the surface of plant roots.
- Their main function is to increase the root's surface area to absorb more water and minerals.
- Red blood cells carry oxygen from the lungs to the all parts of the body.
- They look like round, flat discs that are thicker at the edges than in the middle.
- They are very flexible and can squeeze through thin blood vessels.
- A red pigment called haemoglobin carries oxygen.
- Muscles contract when stimulated by a nerve.
- Muscles are made of muscle fibres that pull at a particular bone to create movement.
- Nerves are connected to the muscle fibres, causing them to move.

Glossary

cellular respiration – the chemical process of using glucose in the presence of oxygen to produce energy together with carbon dioxide and water as by-products

chlorophyll – green pigment used in light absorption in plant nutrition

chloroplast – part of cell containing chlorophyll for photosynthesis

differentiation – become different or specialised

gaseous – of gases or to do with gases

haemoglobin – red oxygen-carrying substance in red blood cells

photosynthesis – the process of food production in a plant through sunlight

vacuole – space in the cytoplasm of a cell containing air, fluid, food particles, and so on

Revision questions

Choose the correct answer.

1. Haemoglobin is a pigment in blood cells that carries:
   - **A** nitrogen
   - **B** oxygen
   - **C** carbon dioxide
   - **D** water (2)

2. Palisade cells contain ... to enable photosynthesis
   - **A** cell sap
   - **B** cellulose
   - **C** chlorophyll
   - **D** cylinder (2)

3. Name two ways in which palisade cells are adapted to their specific function. (4)
4. Root hairs are specialised cells.
   - **a)** Name the function of root hairs. (1)
   - **b)** How are root hairs adapted to absorb water? (4)
5. Explain why red blood cells must be flexible. (2)
6. What is the function of the nerve attached to the muscle fibre? (2)
7. How do muscles move a bone? (3)

TOTAL: 20

Unit 2 Plant nutrition

Objectives

- Describe experiments to determine factors influencing the rate of photosynthesis.
- Describe what happens to the end products of photosynthesis.
- Identify parts of the internal structure of a leaf.
- Describe how the leaf is adapted for photosynthesis.

Introduction

Plants make their own food from simple inorganic compounds such as carbon dioxide and water. Animals feed on plants because they cannot make their own food. In this section you will learn about the process of photosynthesis and how the leaf is suited for photosynthesis.

Photosynthesis

Photosynthesis is the process in which light energy from the Sun is trapped by chlorophyll and used to change carbon dioxide and water into carbohydrates. Oxygen is released into the atmosphere as a by-product.

Photosynthesis can be represented by the following word equation:

$$\underset{\text{reactants}}{\text{carbon dioxide + water}} \xrightarrow[\text{catalysts}]{\text{chlorophyll and sunlight}} \underset{\text{products}}{\text{carbohydrates + oxygen}}$$

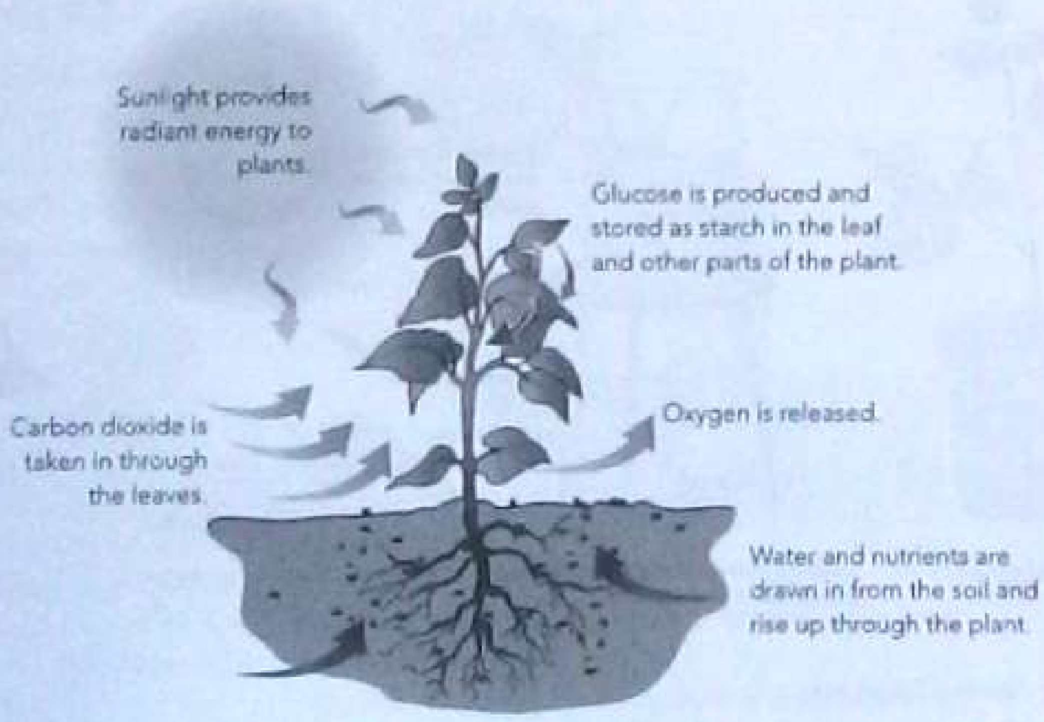


Figure 2.1 The raw materials (reactants and catalysts) and products of photosynthesis

Raw materials of photosynthesis

In order for plants to make food through the process of photosynthesis, they need water, light, carbon dioxide and chlorophyll. These are the raw materials. They are used as follows:

1. Water enters the plant cell through the root hairs of the root. From the root it moves by **diffusion** and **osmosis** into the xylem of the stem and up to the leaf in a continuous **transpiration stream**.
2. Carbon dioxide enters the **stomata** of the leaves. It diffuses into the intracellular spaces between the leaf cells. The carbon dioxide moves into the chloroplasts of leaf cells.
3. Chlorophyll is a pigment found in chloroplasts. The purpose of chlorophyll is to trap sunlight without which photosynthesis cannot take place.
4. Light energy from the Sun is trapped in the chlorophyll molecules of the chloroplasts where it is used to break down carbon dioxide and water molecules and recombine them into glucose molecules. In this way, solar energy is locked up in glucose molecules in the form of chemical potential energy.

The end products of photosynthesis

1. Glucose is converted into starch, the carbohydrates produced by photosynthesis. Starch is stored as a source of energy for plant cells to use when needed. Starch is an indication that photosynthesis has occurred.
2. Oxygen is released into the atmosphere as a by-product and used in respiration.

In the next experiment, you will work in groups to test if photosynthesis has taken place. You will use iodine **solution**, a yellow-brown liquid that reacts with starch to form a substance with a blue-black colour.

Experiment 2.1

Aim: To test a leaf for the presence of starch

Materials: a plant with green leaves, aluminium foil or black paper, methylated spirits, a hotplate or a Bunsen burner, a mug or a beaker, forceps, iodine solution, a dropper, a white tile or white paper

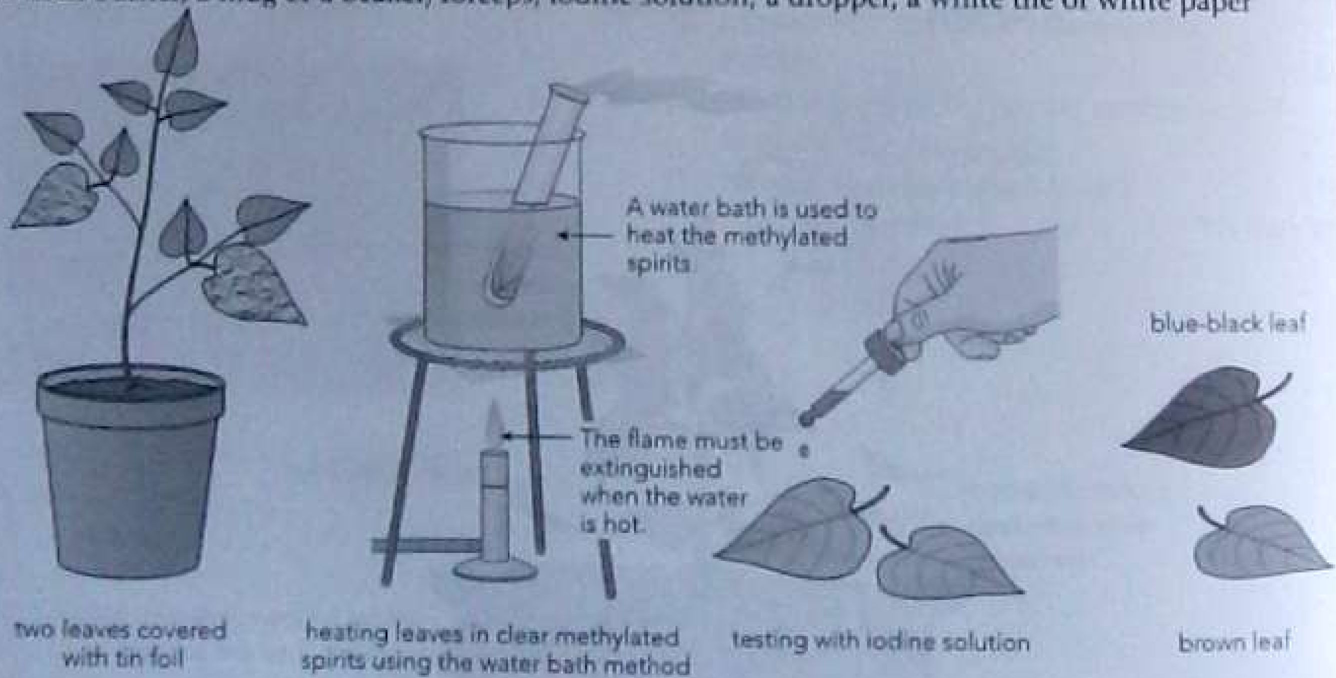


Figure 2.2 Testing for starch

Procedure

1. Cover two leaves of a plant with tin foil so that they get no sunlight at all. Leave them like this for three days.

2. On the fourth day, uncover one of the leaves and let it have four to six hours of sunlight.
3. Pick both leaves and mark them so that you know which leaf had some sunlight and which one was kept in the dark.
4. Dip both leaves in boiling water for two minutes. The boiling water kills the cells and prevents further chemical reactions from taking place.
5. Put the leaves inside a test tube. Cover them with the clear methylated spirits and leave the test tube in boiling water for ten minutes. (Methylated spirits may catch fire if heated directly.)
6. Dip and rinse the leaves in clean warm water.
7. Lay the leaves on a white tile or white paper and cover both leaves with iodine solution.

Questions

1. Compare the colour of the two leaves.
   - What two things does this test show you?
   - Why did you test two leaves instead of one?
2. Copy the table below into your exercise book to record your observations. You can record your conclusions by answering the questions in italics.

Leaf that did not get sunlight	Leaf that got sunlight
Note the colour of the leaf stain.	*Note the colour of the leaf stain.*
Say whether starch was present.	*Say whether starch was present.*
Did photosynthesis take place?	*Did photosynthesis take place?*

Results

The leaf that was exposed to sunlight turned blue-black, but the other leaf remained brown. This shows that plants can make their own food, and that they need sunlight for photosynthesis.

Experiment 2.2

Aim: To show that plants give off oxygen during photosynthesis.

Materials: matches and 2 splints to light up, 2 large basins, 2 test tubes, 2 glass funnels, *Elodea*, or any other type of water plant, a weak solution of water and sodium bicarbonate (baking soda).

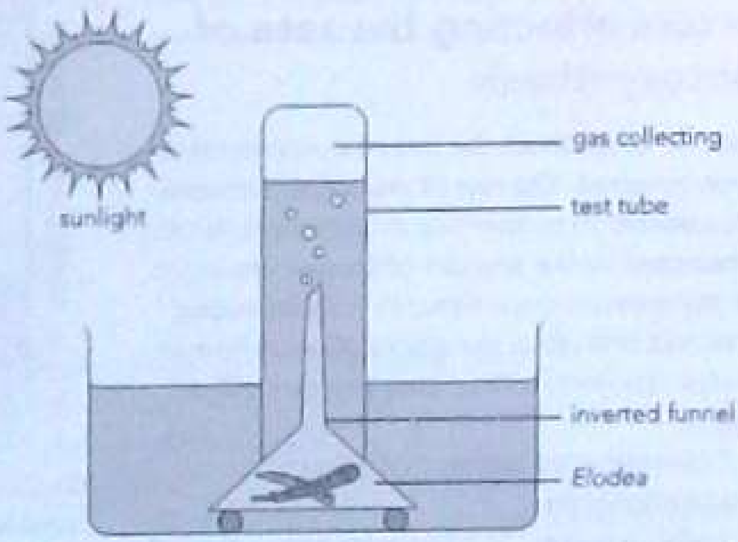


Figure 2.3 Testing for oxygen

Procedure

1. Fill both basins with the weak sodium bicarbonate solution and place a plant in each. (The sodium bicarbonate will provide the plant with a source of carbon dioxide.)
2. Invert the glass funnels and place them over the plants. Fill the funnels with water.
3. Invert a test tube filled with water over each funnel.
4. Place one of the sets in full sunlight and leave it there for at least 8 to 10 hours.
5. Place the other set inside a dark cupboard for 24 hours.
6. After 24 hours, carefully remove the test tubes with your thumb over the openings.
7. Turn each test tube over and insert a glowing splint into the tube.

Results

Oxygen relights a glowing splint. This is used as a test for oxygen.

Questions

1. Describe what happens when the glowing splint is placed into the test tube containing gas.
2. Explain why the flame relights the glowing splint when it is placed in the test tube containing a gas.
3. Why was a glowing splint used in this experiment?
4. What can you conclude from the experiment?

Exercise 2.1

Test what you can remember by answering the following questions:

1. Name the two reactants in photosynthesis.
2. Where do plants get the carbon dioxide they absorb?
3. How do plants absorb water? From where does it come?
4. What is chlorophyll and where is it found?
5. Name the form of energy that comes from the Sun.
6. Name the two catalysts in the series of chemical reactions that take place during photosynthesis.

Factors affecting the rate of photosynthesis

When we speak about the rate of a process there is time involved. The rate of photosynthesis can be considered to be how fast it takes place. It can be measured by the amount of glucose produced by a plant over a given time. By understanding the factors that affect the rate of photosynthesis, scientists and farmers can increase the yield of crops.

Environmental factors that affect photosynthesis are:

1. **Light intensity**. As light increases, so does the rate of photosynthesis increase.
2. **Temperature**. As temperature increases, the rate of photosynthesis increases. Enzymes control photosynthesis, allowing the rate to reach an optimum level. If the temperature increases beyond the optimum level, it will damage the enzymes with the result that the rate of photosynthesis drops.
3. **Carbon dioxide concentration**. As the carbon dioxide concentration increases, so does the rate of photosynthesis increase. Insufficient carbon dioxide means that the rate will be lower. Many commercial growers of fruits and vegetables (for example tomato growers) use greenhouses with a carbon dioxide enriched atmosphere to increase production.
4. **Chlorophyll concentration**. Magnesium is a macronutrient in plants and is necessary for the formation of chlorophyll. When there is a magnesium deficiency the leaves turn yellow and a condition called **chlorosis** develops. The lack of chloroplasts in these leaves therefore affects the rate of photosynthesis negatively.

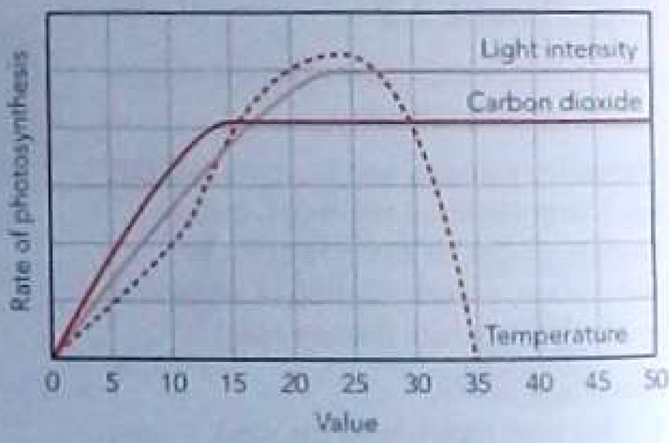


Figure 2.4 Environmental factors affect the rate of photosynthesis

There are various investigations that can be used to measure the rate of photosynthesis. Each investigation depends on the amount of oxygen produced during the reaction. You will count the oxygen bubbles produced during the reaction as a measure of how much oxygen is produced.

Experiment 2.3

Aim: To observe the rate of photosynthesis

Materials: a large basin, a test tube, a glass funnel, *Elodea*, or any other type of water plant, an electric lamp, a tape measure, a clamp stand with a boss and clamp, a stop watch

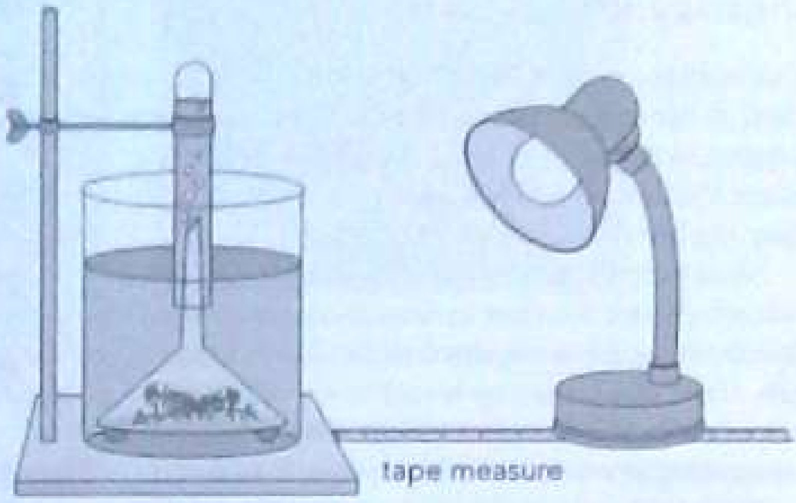


Figure 2.5 Measuring the rate of photosynthesis

Procedure

1. Cut *Elodea* stems at an angle and use your fingers to crush the end of the stem.
2. Fill the basin with water.
3. Place the plant in the water as shown in the diagram.
4. Invert the glass funnel and place it over the plant.
5. Fill the funnel with water.
6. Invert a test tube filled with water over the funnel.
7. Place a light next to the apparatus and leave the apparatus for at least eight hours.
8. Place the tape measure as shown in Figure 2.5. Measure how far the light is positioned from the apparatus.
9. Look for a stream of bubbles coming from the cut end of the *Elodea*.
10. Count the number of bubbles produced in one minute. Repeat for a second minute. Repeat for a third minute. Count and calculate the mean rate of bubble production as before.
11. Move the light further away from the apparatus. Leave for 2 minutes and then take counts of the number of bubbles produced in one minute. Repeat the count and calculate the mean rate of bubble production as before.
12. Repeat instruction 10 and 11 another 5 times.

Questions

1. What are your results in terms of bubble rate?
2. What gas do we assume is inside the bubbles?
3. Where has the gas come from?
4. Why does an increasing bubble rate suggest an increasing rate of photosynthesis?
5. Identify the independent and dependent variables in the investigation.
6. What effect has light intensity had on the rate of photosynthesis?
7. How would you make the investigation more reliable?
8. Explain why you need to leave the apparatus for 2 minutes after moving the light away from the apparatus.

Further investigation

You can also test for other factors affecting the rate of photosynthesis. For example:

- Test for temperature, by using hot water, ice, and a thermometer.
- Test for carbon dioxide by using potassium hydrogen carbonate in powder form or in solution.

More on the end products of photosynthesis

As soon as glucose is formed in the leaves, it is stored in the form of starch. Starch cannot dissolve in water, so it cannot be lost through the stomata. During the day, when photosynthesis is taking place, the leaves contain lots of starch.

Some parts of the plant do not contain chlorophyll and therefore cannot photosynthesise. Carbohydrates are transported as glucose to these parts of the plant. Glucose is sent to growth points such as roots, leaf buds and flowers. This process of transporting glucose is known as translocation.

Plants can store excess glucose for future use in their roots, stems, leaves and seeds. The parts of sweet potatoes and potatoes we eat are examples of organs that store large amount of starch.

Plants can also store food in different forms, such as starch, sugars or lipids. Carbohydrates can also be converted into structural molecules such as cellulose found in cell walls. Cellulose forms the fibrous part of plants. (This fibre is essential in our diet as it promotes healthy bowel movements.)

Oxygen is released as a by-product into the atmosphere through the stomata of the leaves.

Activity 2.1

Work in pairs to answer the following questions:

1. A man sprayed a field with a chemical that destroys chlorophyll. Explain what effect this will have on plants and animals in the environment.
2. A leaf was partly covered with black paper and left in the sunlight for four to five hours. It was then tested for starch.
   a) What was the aim of this experiment?
   b) Was it a fair test? Explain your answer.
   c) What are the expected results? Explain your answer.
   d) How would you test for starch in the leaf?
3. Write down the word equation for photosynthesis.
4. Below is a list of statements about plants. Discuss the statements and decide which are true and which are false.
   a) Plants get their food from the soil.
   b) Animals would die if all plants disappeared.
   c) If the Sun stopped giving light, there would be no life on the Earth.
   d) An albino maize plant has no chlorophyll, so it cannot grow.
   e) Plants need carbon dioxide to live.

The internal structure of a leaf

The internal structure of leaves is provided by many different cells that are arranged in a specific order. Leaves are specifically adapted to make sure that photosynthesis occurs properly.

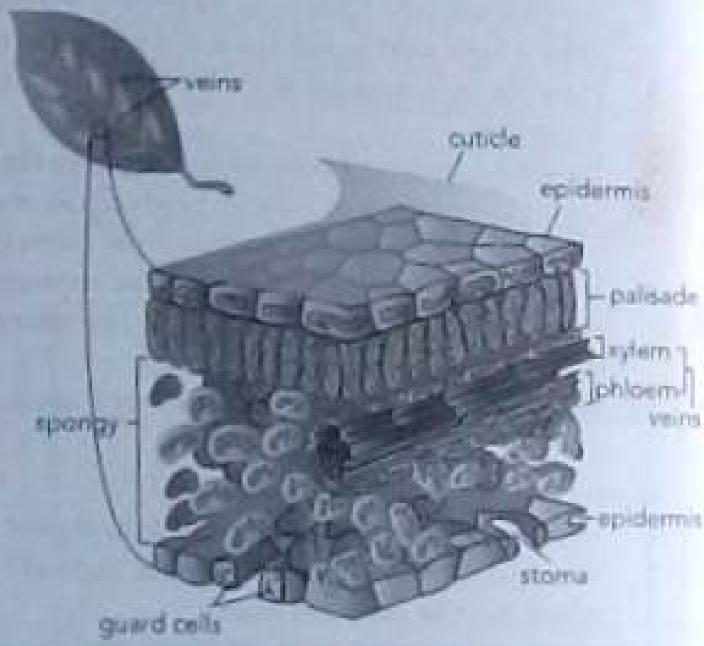


Figure 2.6 The internal structure of a leaf

The upper and lower layers of the leaf are single layers of **epidermis** cells. A waxy layer, the cuticle, covers the epidermal layer. The function of the cuticle is to prevent water being lost through **evaporation** from the leaf tissues.

The inner part of the leaf is known as the **mesophyll**. The mesophyll is made up of two distinct layers. The upper half of the mesophyll has elongated cells called the palisade cells. The palisade cells are closely packed together and each of them contains many chloroplasts carrying out photosynthesis.

The lower half of the mesophyll is made of spongy cells. They are irregularly arranged cells with fewer chloroplasts.

The mesophyll has many air spaces, which allow carbon dioxide and oxygen to diffuse to and from the leaf cells. The **veins** running through the leaf carry water and food to and from the leaf. The **xylem** carries water to the leaf and **phloem** carries food away from the leaf. Xylem and phloem are known as vascular tissue.

On the lower epidermal layer, there are small pores that control the exchange of gases and water between the leaf and the atmosphere. These small pores are called stomata (singular **stoma**). The pores are surrounded by two guard cells that control their opening and closing. This controls the rate of gaseous exchange.

Figure 2.7 The guard cells surrounding a stoma

Gases are exchanged during the processes of photosynthesis and respiration through the leaf. Water is also lost through the stomata by **transpiration**.

In the next experiment you will work in groups to learn first-hand about the internal structure of the leaf.

Experiment 2.4

Aim: Investigate the internal structure of a leaf

Materials: a microscope or hand lens, *Geranium* or *Elodea* leaves

Procedure

1. Prepare a wet mount for the leaves.
2. Place the mount on the stage of the microscope or examine it through a hand lens.
3. List what you see, using Figure 2.6 above for reference. Discuss the list in your group.
4. Draw a diagram of the leaf as seen under the microscope and show the different cells. Label your diagram.

Experiment 2.5

Aim: Investigate the external structure of a leaf

Materials: a hand lens, *Geranium* leaves

Procedure

1. Read through the following list of structures and identify the parts on the *Geranium* leaf.
   - The broad, flat part of the leaf is called the **lamina**. The flat surface allows the sunlight to reach all parts of the blade so that photosynthesis can occur.
   - The edge of a leaf is called the **margin**. This edge can either be smooth, rounded or have jagged points.
   - Within the leaf there are veins to carry food and water. The veins form a net-like pattern supporting the blade.
   - The large central vein is called the **midrib**. This runs from the base of the blade to the leaf tip.

- Some leaves do not have a central vein, but they have a few main veins. The leaf is attached to the stem by a **petiole**. The petiole bends so that the blades receive the most sunlight for photosynthesis.
- There are two small flaps that grow at the base of the petiole and they are called the **stipules**. Their main function is to protect the young blade as it develops.

2. Draw a diagram of your leaf showing all the relevant labels.

Leaves are suited for photosynthesis

Leaves have a number of features that make them suitable organs for photosynthesis. The flattened structure of the leaf provides a large surface for absorbing light. The cells in the upper and lower epidermis are transparent to allow light to penetrate easily. In the lower epidermis the stomata allow gases to enter and leave the leaf. The stomata are surrounded by guard cells that open and close to regulate the exchange of gases. Leaves are thin for easy diffusion of carbon dioxide to the mesophyll cells where photosynthesis takes place.

The palisade mesophyll cells are packed tightly in rows. The cell shape and arrangement allow more cells to be exposed to sunlight. Palisade mesophyll cells contain many chloroplasts. The spongy mesophyll below the palisade cells consists of loosely packed, irregularly shaped cells. The large air spaces between the cells allow rapid diffusion of carbon dioxide to all photosynthesising cells. The spongy mesophyll also contains chloroplasts.

The leaves contain many veins, consisting of xylem and phloem. The xylem carries water and mineral salts absorbed from the soil to the mesophyll cells. The phloem carries the organic food, manufactured in the leaf during photosynthesis, to other parts of the plant.

Summary

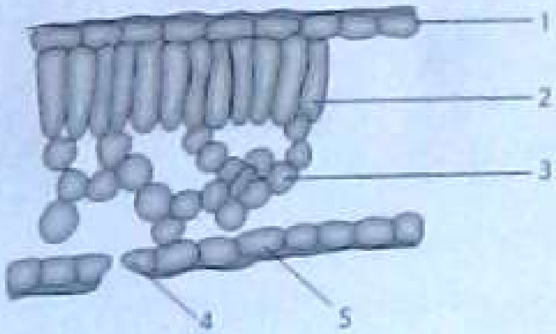
- Photosynthesis is the process in which light energy from the Sun is trapped by chlorophyll and used to change carbon dioxide and water into carbohydrates. Oxygen is released into the atmosphere as a by-product.
- Starch is an indication that plants can make their own food and that they need sunlight for photosynthesis.
- Environmental factors that affect photosynthesis are: light intensity, temperature, carbon dioxide and chlorophyll.
- As soon as glucose is formed in the leaves, it is stored as starch. Starch cannot dissolve in water, so it cannot be lost through the stomata.
- Carbohydrates are transported as glucose to parts of the plant that do not contain chlorophyll.
- Glucose is sent to growth points such as roots, leaf buds and flowers. This process of transporting glucose is known as translocation.
- Plants can store excess glucose in their roots, leaves and stems in the form of starch for future use.
- Plants can also store food in different forms, such as starch, sugars or lipids.
- Carbohydrates can also be converted into structural molecules such as cellulose found in cell walls.
- Oxygen is released into the atmosphere as a by-product through the stomata of the leaves.
- The internal structure of the leaf is provided by many different cells that are arranged in a specific order. The leaf is specifically adapted to make sure that photosynthesis occurs properly.
- Leaves have features such as a large surface area, stomata, palisade cells and air spaces, making them suitable organs for photosynthesis.

Glossary

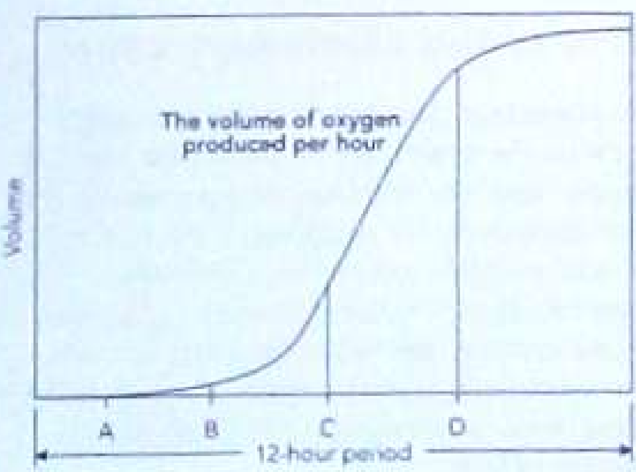
chlorosis – a condition in plants where they lose their green colouring and become yellow
diffusion – the movement of a substance from an area of higher concentration to an area of lower concentration
epidermis – outer layer
evaporation – the change of a substance from a liquid state to a gas
lamina – broad, flat part of a leaf
margin – edge of a leaf
mesophyll – inner tissue of a leaf
midrib – large central vein of a leaf
osmosis – the movement of a solvent (water) from where the solvent (water) is present in a higher concentration through a semi-permeable membrane to where the solvent (water) is present in a lower concentration
petiole – attaches the stem to the leaf
phloem – plant vessels carrying food produced in the plant leaves to the rest of the plant
stipule – flap at the base of the petiole
stoma – pore in the epidermis of a leaf (plural: stomata)
transpiration – a plant's loss of water through evaporation at the stomata
transpiration stream – the flow of water through a plant from its roots to its leaves
vein – the transport system in plants is made up of veins
xylem – plant vessels carrying water to the leaf

Revision questions

1. The part of a cell where photosynthesis takes place is called the:
   A vacuole B cell membrane
   C chloroplast D nucleus (2)
2. The substance that makes cell walls strong is:
   A cell sap B cellulose
   C cytoplasm D water (2)
3. Study the diagram of a leaf below and answer the questions that follow:



   a) Provide suitable labels for parts 1 to 5. (5)
   b) Explain how parts 1, 2, and 3 are suited to the function of photosynthesis and providing food to the plant. (10)
   c) Explain why leaves are wide and flat. (2)
   d) Leaves need water to keep their shape. Describe how the leaves absorb water. (4)
4. The volume of oxygen produced per hour by pond weed in a pond was measured over a 12-hour period. The results are shown in the graph below:



   a) Which letter on the graph represents 12h00 noon? (1)
   b) Give a suitable reason for your answer in a) above. (2)
   c) Identify the variable being tested, that is, the dependent variable. (1)
   d) Identify the independent variable. (1)

TOTAL: 30

Unit 3 Human nutrition

Objectives

- Draw and label components of the human alimentary canal and associated organs.
- Identify components of the human alimentary canal.
- List the functions of the components of the human alimentary canal.
- Name the different types of human teeth and their functions.
- Describe mechanical and chemical digestion.
- Explain the importance of digestion.
- Describe the function of enzymes in human nutrition.
- Identify the end products of digestion.

Introduction

You need food to survive. Food gives you energy and allows you to grow and replace cells in your body. The food you eat is broken into smaller units in the digestive system. It is these small units that the body uses for growth, repair and energy.

Parts of the alimentary canal

The **alimentary** canal is a long, hollow tube that runs from the mouth, at one end, to the **anus**, at the other end. The following organs make up this canal: the mouth, the oesophagus, the stomach, the small intestine and the large intestine.
As food moves down the alimentary canal from the one opening (mouth) to the other opening (anus), various **accessory organs** of the digestive system produce substances to facilitate the digestion of food.

Mouth

The mouth consists of the lips in the front, the cheeks at the sides and the upper and lower jaws. Each jaw has a set of teeth in it. The lips and teeth prevent the food from falling out of the mouth. The lower jaw moves to facilitate chewing. The teeth tear, chew and grind the food before it is swallowed. Saliva from the salivary glands is mixed into the food.

Oesophagus

The oesophagus is a tube that connects the mouth to the stomach. When you swallow food, the oesophagus muscles contract and relax in waves to push the **bolus** of food to the stomach. This movement is called **peristalsis**.

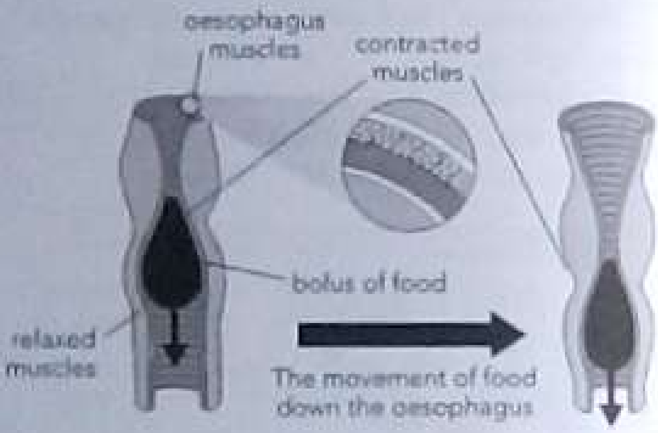


Figure 3.1 Process of peristalsis

Stomach

The stomach is an organ in the form of a bag with thick muscular walls. The stomach wall is elastic and this allows it to increase in volume three times or more during a large meal. The muscular wall mixes the food with digestive juices in the process of digestion. The gastric glands are stimulated to secrete gastric juice and hydrochloric acid when food enters the stomach.

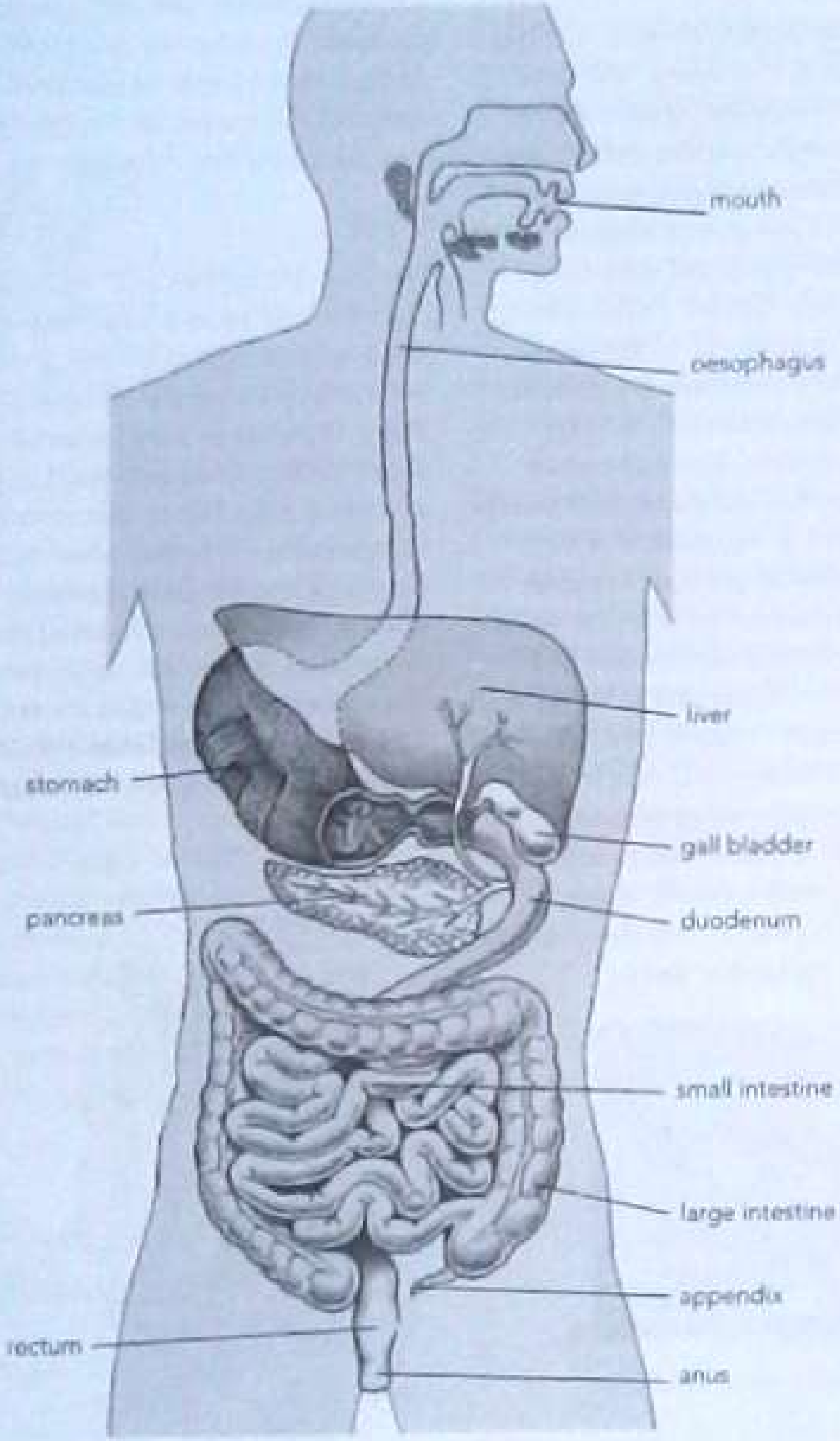


Figure 3.2 The digestive system

Hydrochloric acid kills any bacteria and provides an acid medium to change inactive pepsinogen into active pepsin. Pepsin digests proteins into polypeptides. Hydrochloric acid hydrolyses sucrose into glucose and fructose. Rennin, an enzyme present in children, changes soluble milk protein caseinogen into insoluble casein. Intrinsic factor, also produced by the gastric glands, is needed to absorb vitamin B12. The food is liquidised during peristalsis into a thick liquid called **chyme**.

Small intestine

The small intestine of an adult is about 5 m long and connects the stomach to the large intestine. The small intestine is divided into three regions: the duodenum, the jejunum and the ileum. Two ducts from accessory digestive organs enter the duodenum: the bile duct brings bile from the liver and gall-bladder, and the pancreatic duct brings pancreatic juice from the pancreas. Finger-like structures called **villi** (singular villus) are found on the inside of the small intestine wall. Almost all the absorption of nutrients occurs through the villi of the small intestine. Along the whole length of the small intestine are glands that secrete digestive **enzymes**. The waving motion of the villi together with segmental peristalsis ensures that all chyme comes into contact with the small intestine's surface. The epithelium layer of the villi also contains *microvilli*, helping to increase the absorptive and digestive surface area of the small intestine. The epithelium has only one cell layer, which provides a thin absorptive surface so that nutrients can pass quickly into the blood capillaries. The villi are well supplied with a network of tiny blood capillaries and the absorbed nutrients are thus quickly carried away.

Figure 3.3 a) A surface view of the villi

Large intestine

An adult's large intestine is about 1.5 m long and it consists of an ascending section, a transverse section and a descending section. The large intestine absorbs water and minerals into the bloodstream. The end of the colon is called the **rectum** and it opens to the exterior at the anus.

A circular muscle, the anal **sphincter**, surrounds the **anus**, the opening at the end of the alimentary system. Waste products and solid undigested food stored in the rectum in the form of **faeces** finally pass out of the body through the anus.

Liver

The liver lies in the upper right-hand corner of the abdomen, partly covering the stomach. It has two lobes, a larger right lobe and a smaller left lobe. Liver cells produce the alkaline fluid called **bile**. Bile is made up of water, bile salts, bile pigments (from broken down red blood cells), cholesterol and other salts. Bile is used to **emulsify** fats and to neutralise the hydrochloric acid that was produced and added in the stomach. The liquid fats are broken into very small droplets through the process of emulsification, thereby increasing the surface area on which the fat-digesting enzyme lipase can act. Excess amino acids (proteins) are **deaminated** into glucose and urea. The glucose

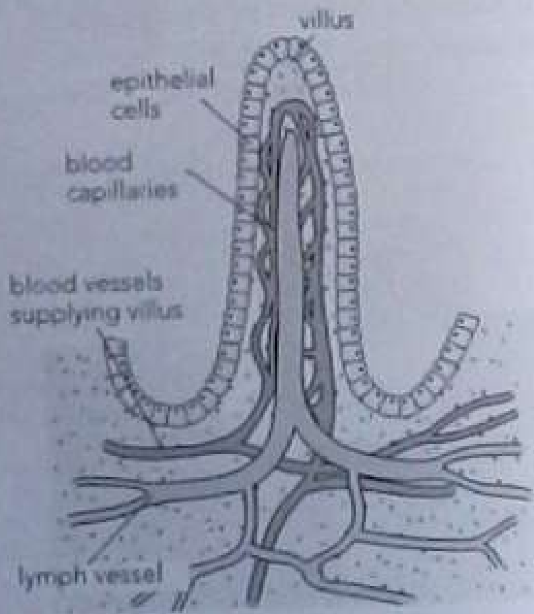


Figure 3.3 b) A longitudinal section of a villus

is converted to glycogen and the urea is excreted in the kidneys. Poisonous substances, such as insecticides, alcohol and food preservatives, are absorbed and neutralised in the liver.

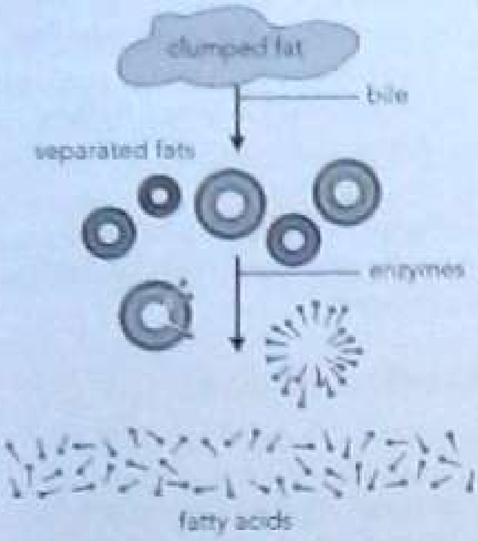


Figure 3.4 Bile is used to emulsify fats.

Gall-bladder

The gall-bladder is a bag attached to the lower surface of the liver. It stores the bile that has been produced in the liver and which is continuously released into the gall-bladder through the bile duct. When large amounts of bile are needed for digestion, the gall-bladder contracts to force bile through the common bile-pancreatic duct into the duodenum. The two main functions of the gall-bladder are to store bile until it is needed and to concentrate bile by reabsorbing water and ions.

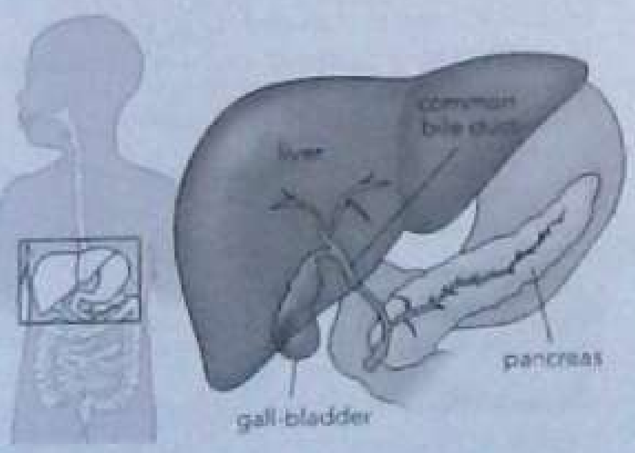


Figure 3.5 The position of the liver, the gall-bladder and the pancreas.

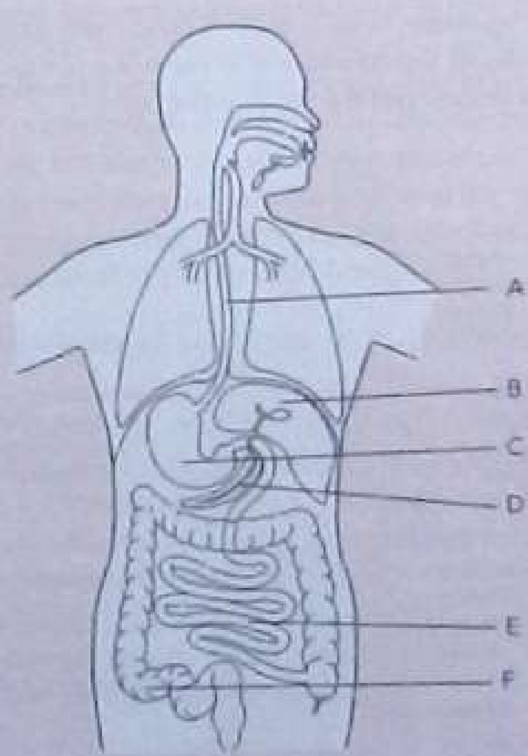
Pancreas

The pancreas is a gland situated in the curve formed by the duodenum. The pancreas has both **exocrine** and **endocrine** functions. It is an exocrine gland because it secretes enzyme-rich pancreatic juice into the duodenum for digestion *through a duct*. It is also an endocrine gland, because it secretes the **hormones** insulin and glucagon *directly into the bloodstream* to control blood glucose levels in the blood. Bicarbonate ions secreted by the pancreas help neutralise the acidic chyme as it enters the duodenum.

Pancreatic juice contains the following enzymes: Pancreatic **lipase** hydrolyses lipids to glycerol and fatty acids. Pancreatic **amylase** hydrolyses any remaining starch to maltose. Pancreatic juice contains **inactive trypsinogen**, which is converted to **active trypsin** by enterokinase, present on the epidermal cells of the duodenum, to hydrolyse polypeptide chains into tripeptides and dipeptides.

Exercise 3.1

This diagram shows part of the human digestive system.



1. Identify labels A to F.
2. Some functions of organs in the human digestive system are given below. Give the letter in the diagram, together with the correct name of the organ, matching up with each of the functions:
   a) stores extra sugar
   b) transports food to the stomach
   c) absorbs much of the water into the blood stream
   d) mixes and digests food.

Processes involved in nutrition

There are various processes involved in moving, mixing and digesting food in the alimentary canal. Large pieces of food are broken down into smaller units, so that your body can absorb it into the bloodstream. This whole process of taking in and using food substances or nutrients is called **nutrition**.

Nutrition in humans occurs in five stages:

1. **Ingestion**: Food is put into the mouth where it is chewed into smaller pieces by the teeth, mixed with saliva and swallowed.
2. **Digestion**: Food is broken down into simpler, soluble substances inside the body in the stomach and the small intestine.

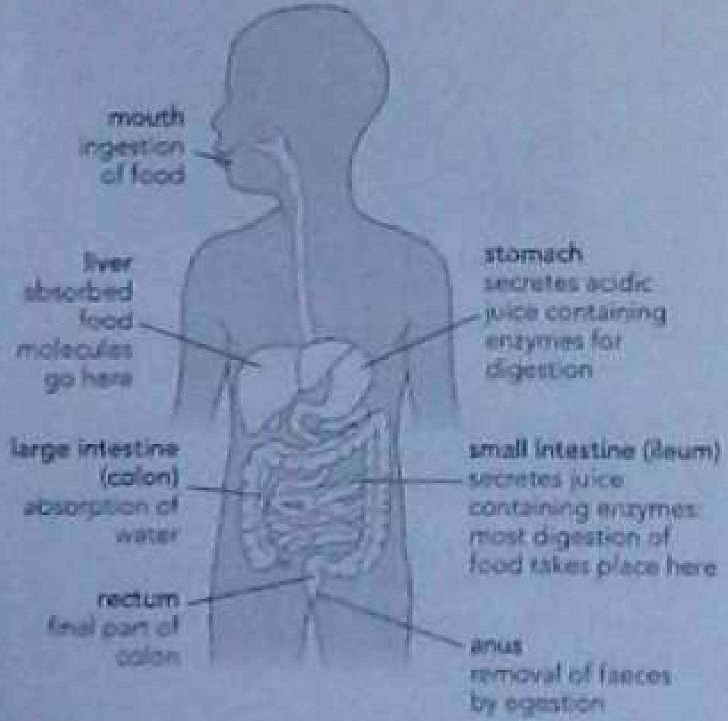


Figure 3.6 The main processes of nutrition

3. **Absorption**: Soluble food substances are taken up into the bloodstream in the small intestine and the large intestine.
4. **Assimilation**: Soluble food substances move from the bloodstream into the cells and are incorporated into cell structures.
5. **Egestion**: Undigested food substances and waste called faeces are egested from the body. (Also called defecation.)

Types of teeth and their functions

The teeth are used to bite, tear, crush and grind food into smaller pieces. There are four main types of human teeth. Each type is different in structure and performs a specific function:

1. Incisors (*I*): Four front teeth in the upper jaw and four front teeth in the lower jaw. They are chisel-shaped and are used for biting and cutting food.
2. Canines (*c*): These are single teeth in each half jaw next to the incisors. They are pointed and are used for gripping and tearing food.
3. Premolars (*pm*): There are two behind the canines on the upper and lower jaws, thus totalling eight. Together with the molars, they form the cheek-teeth and have flattened surfaces for crushing and grinding food.
4. Molars (*m*): There are six molars found at the back of the upper jaws and six in the lower jaws. They have flattened surfaces for crushing and grinding food.

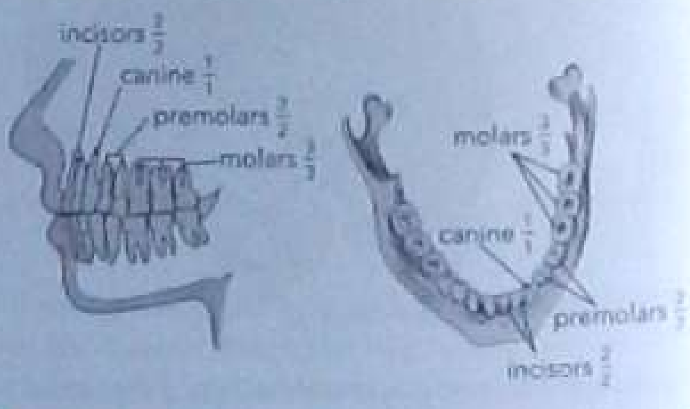


Figure 3.7 Two views of adult human teeth: from the side and the lower jaw from the top

Babies are usually born without any teeth. During the first few years of your life, a set of milk teeth develops. Between the ages of six and twelve, your milk teeth fall out, one by one, and are replaced by a set of permanent (adult) teeth. The milk teeth consist of incisors, canines and pre-molars. The permanent set of teeth consists of incisors, canines, premolars and molars.

Activity 3.1 You and your teeth

The full number of teeth you possess can be given by a **dental formula**. Since each half of a jaw is symmetrical, only one half of each jaw needs to be included in the formula. You have seen above that the four types of tooth are indicated by their initial letters (*i*, *c*, *pm*, *m*).

The dental formula for an adult human is:

Upper jaw	*i*2 *c*1 *pm*2 *m*3	2 1 2 3
Lower jaw	*i*2 *c*1 *pm*2 *m*3	2 1 2 3

1. What do the letters *i*, *c*, *pm* and *m* represent?
2. Discuss the structure and function of the different teeth.
3. How many teeth should there be in an adult's mouth in total? Explain how you arrived at your answer.
4. State the dental formula for a complete set of milk teeth.
5. Why is the dental formula for a human baby different to that of a human adult?
6. Draw and label a full set of human milk teeth on the lower jaw.

Digestion

The process of breaking down food into a usable dissolved form in the digestive system is called digestion. There are two types of digestion, namely, mechanical and chemical digestion.

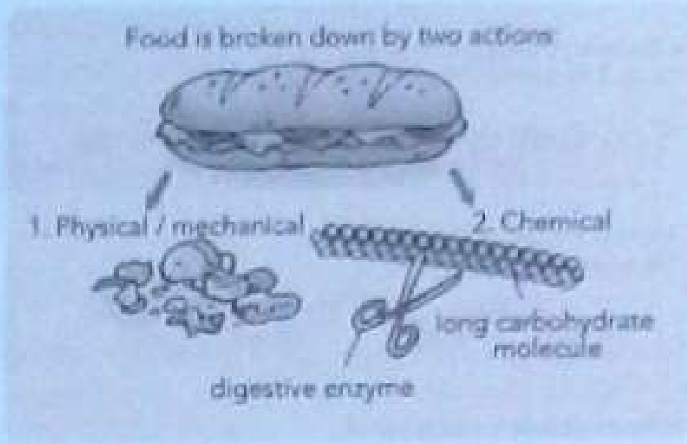


Figure 3.8 Mechanical and chemical digestion

Mechanical digestion

Mechanical digestion is about physically breaking down food into smaller pieces. The teeth chew and grind the food into smaller pieces. This increases the surface area of food for the digestive enzymes to work on chemically. The stomach and intestine muscular walls also mix the food mechanically by contracting and relaxing. You have learnt that this movement is called peristalsis.

Chemical digestion

Chemical digestion happens through the use of digestive enzymes, breaking down small pieces of food into even smaller, soluble ones. The process begins in the mouth through saliva which contains enzymes. The stomach and small intestine contain digestive enzymes that **catalyse** the breaking up of food into particles small enough to dissolve in water and be absorbed into the bloodstream.

The function of enzymes in digestion

Starch, proteins, and lipids (fats) are broken down by enzymes during chemical digestion. Enzymes are biological catalysts speeding up the digestive process in the alimentary canal. Enzymes are extremely efficient as they work only on specific nutrients. Enzymes which act on:

- proteins are called **proteases**
- carbohydrates are called **carbohydrases**
- lipids (fats) are called **lipases**.

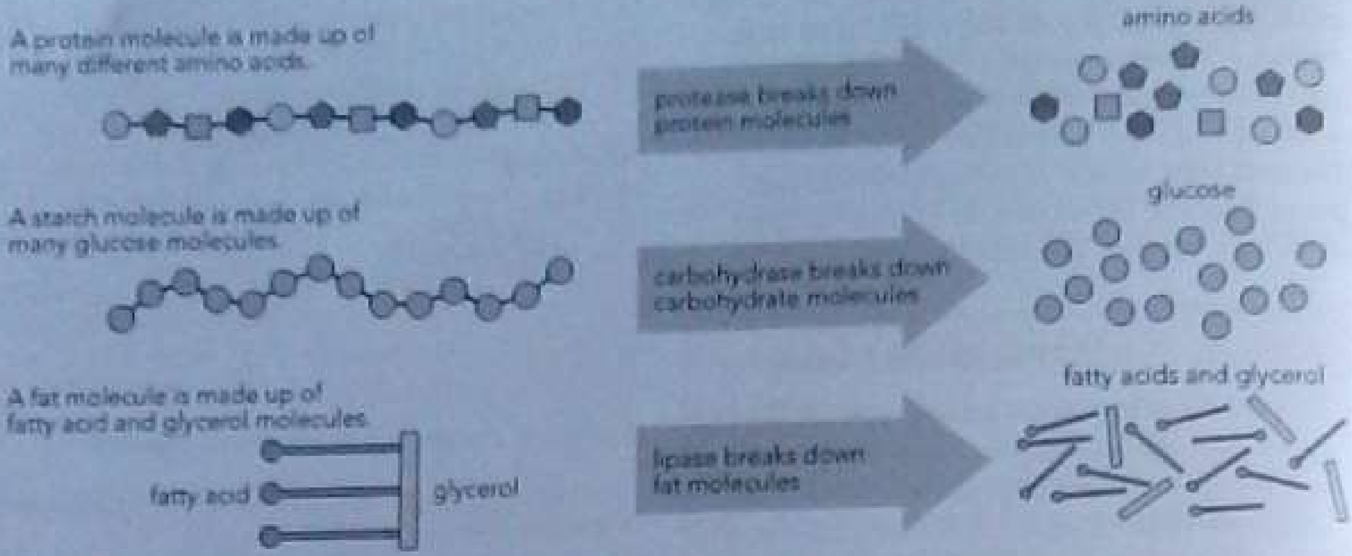


Figure 3.9 Enzymes are responsible for digesting specific nutrients.

Each of these major groups of enzymes includes specific enzymes acting on specific substances.

For example, the enzyme amylase is a carbohydrase catalysing the breakdown of starch into maltose. Maltose is then further broken down into glucose by the enzyme maltase. This is shown in the enzyme reaction below:

$$\text{starch} \xrightarrow[\text{enzyme action}]{\text{amylase}} \text{maltose} \xrightarrow[\text{enzyme action}]{\text{maltase}} \text{glucose}$$

We call the substance on which the enzyme acts the **substrate**. The substance resulting from the reaction is the product.

You will notice that the enzymes are usually named by replacing the end of the name of the substrate on which it acts with '*-ase*' (maltose becomes malt*ase*).

Experiment 3.1

Aim: To examine the action of amylase on starch

Materials: 2 tins or beakers, Visking tubing (cellulose tubing), 10 cm^3 of a starch solution, 1 cm^3 of amylase enzyme, a pipette, Benedict's solution, iodine solution, water, a spotting tray or a white tile

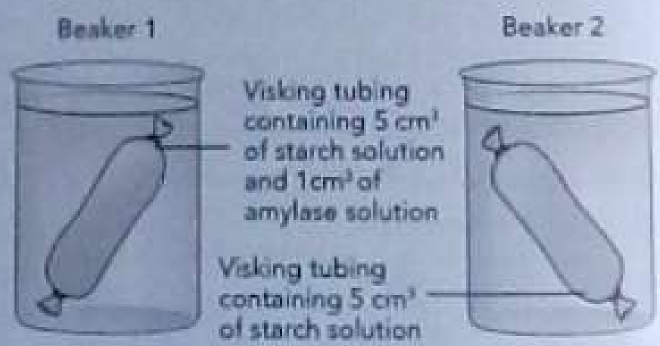


Figure 3.10 Investigating the action of amylase on starch

Procedure

1. Set up the apparatus as shown in Figure 3.10.
2. The Visking tube in Beaker 1 contains 5 cm^3 of a starch solution and 1 cm^3 of amylase solution, while the Visking tube in Beaker 2 contains 5 cm^3 of starch solution only.
3. Wash the outside of the two sections of tubing with water to remove any external traces of starch before placing them in their separate beakers.

4. Leave the tubes in the beaker at room temperature for five minutes.
5. Test the water in the beakers and the Visking tubing sections for both starch and water.
6. Repeat the two tests after 20 minutes. Record your results in a table as shown below:

Time	Result with iodine solution	Result with Benedict's solution	Conclusion
5 minutes			
20 minutes			

Results

The tubing in Beaker 1 contained starch and amylase at the beginning. At the end of the experiment, starch was present inside the tubing, but not outside in the beaker. Glucose was present both inside and outside the tubing.

The tubing in Beaker 2 contained starch only at the beginning. At the end of the experiment, starch was present inside the tubing, but not on the outside in the beaker. Glucose was not present inside nor outside the tubing.

Questions

1. Was any starch or glucose present outside the tubing sections in Beaker 1 and Beaker 2 at the beginning of the experiment?
2. Was any starch or glucose present outside the tubing sections after 20 minutes?
3. Why was there no starch present in the water in Beaker 1?
4. Explain why there is glucose outside the tubing.
5. Identify the independent variable of the experiment.
6. What can you conclude from the experiment?

End products of digestion

During digestion, carbohydrates, proteins and lipids (fats) are broken down into simple units that are then absorbed into the bloodstream to be used in the body or stored. You have learnt about the end products above. The table below provides a summary:

From	To
carbohydrates	simple sugars
proteins	amino acids
fats	fatty acids and glycerol

- **Carbohydrates** are digested by enzymes into simple sugars such as glucose, fructose and galactose. These are used during cellular respiration to provide energy for cellular activities.
- **All proteins** are broken down into amino acids to be used for growth, repair and replacement of cells, making enzymes and hormones.
- **Fats** are broken down into fatty acids and glycerol. These are used to form cell membranes, to provide fuel for cell reactions or to surround and protect organs.

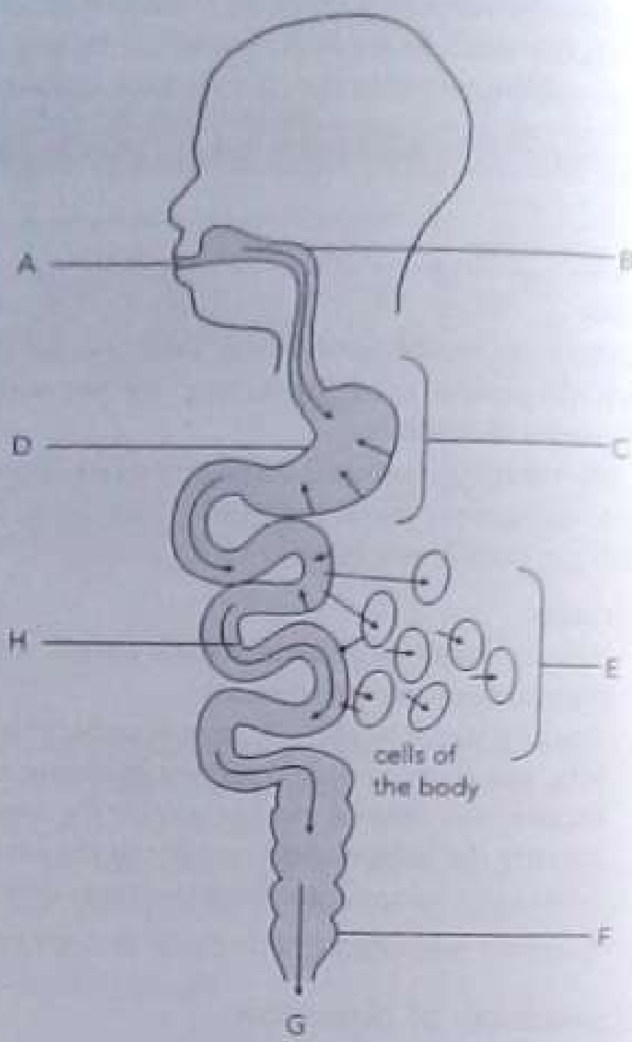
The importance of digestion

Digestion is important as this is the way in which you receive nourishment to keep your body healthy. When you have a balanced diet, nutrients are efficiently digested in the digestive system. Nutrients are absorbed from the small intestine into the bloodstream. All blood carrying food from the digestive system then goes to the liver. In the liver, any excess food is stored in the form of glycogen. From the liver, this nutrient-rich blood returns to the heart that pumps it to the rest of the body. When you do not eat properly, it affects your digestive system and causes problems such as bloating, gas, constipation, diarrhoea or a cramping tummy.

Exercise 3.2

Study the diagram in the right-hand column of the processes occurring in the human digestive system. Examine it and answer the questions that follow.

1. Name processes A, C, E and F.
2. List the parts of the body through which a piece of bread you have eaten passes.
3. Where is water absorbed?
4. What passes out at G? Explain what process this is.
5. Differentiate between mechanical and chemical digestion.
6. Consider the process of mechanical digestion.
   a) In which parts of the diagram does mechanical digestion occur? Explain in full.
   b) Describe the importance of mechanical digestion.
7. Consider the process of chemical digestion.
   a) In which parts of the diagram on the right does chemical digestion occur? Explain in full.
   b) Describe the importance of chemical digestion.



Summary

- The alimentary canal is composed of the mouth, oesophagus, stomach, small intestine, large intestine, rectum and anus.
- The structure of each component of the alimentary canal is adapted to its function.
- Digestion is the process of breaking down food into a usable dissolved form.
- Mechanical digestion involves the physical breaking, crushing and mashing of food.
- Chemical digestion involves the mixing of food with digestive juices and enzymes.
- Enzymes are organic and biological catalysts regulating chemical reactions in living cells.
- In the digestive system, an enzyme combines with its substrate, breaking it down into smaller products.
- Ingestion takes place through the mouth, and both mechanical and chemical digestion begin here.
- Peristaltic action moves food through the oesophagus and into the stomach.
- In the stomach, food is reduced to a liquid mixture called chyme.
- Carbohydrates are digested to maltose by amylase. Maltase digests maltose into glucose, the final product of carbohydrate digestion.

- Proteins are digested by proteases into amino acids as end products of protein digestion.
- Fats are emulsified by bile salts and then further broken down into fatty acids and glycerol by the enzyme lipase.
- The final products of digestion are absorbed through the villi in the small intestine.

Glossary

accessory – in this context, not a primary part of the alimentary canal, but additional to or associated with it

alimentary – relating to nourishment

anus – the opening at the end of the alimentary canal

bile – the greenish fluid secreted by the liver to emulsify fats

bolus – soft ball of food that has been chewed

catalyse – speed up a chemical process without undergoing permanent change

chyme – food that has been chewed and partly digested

deaminate – to remove the amino group from the amino acid molecule

dental formula – a formula that sums up the type of teeth in one half of a jaw

emulsify – in digestion, it is to break up fats into small droplets to be acted upon by enzymes

endocrine – secreting directly into the bloodstream

enzyme – a digestive enzyme is an organic, protein catalyst that regulates digestion

exocrine – secreting through a duct

faeces – undigested food and waste products that pass out of the body through the anus

hormone – a substance produced in an organism that is transported in tissue like blood to regulate certain functions

nutrition – the process of taking in and using food substances, that is, nourishment

peristalsis – the involuntary wavelike movement propelling the contents of the alimentary canal

rectum – the end of the colon terminating in the anus

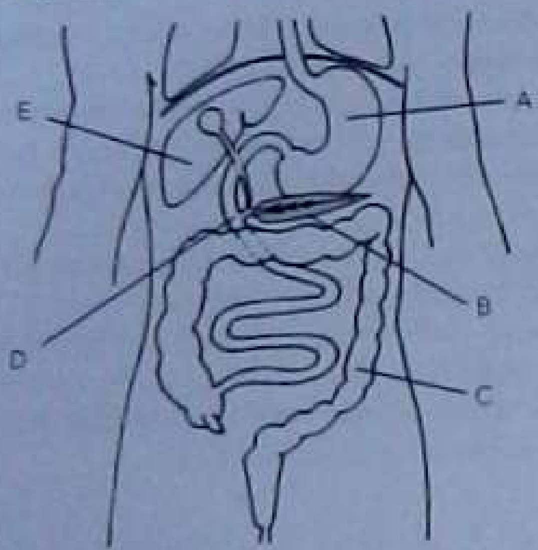
sphincter – a circular muscle that surrounds an opening such as at the anus

substrate – substance upon which an enzyme acts

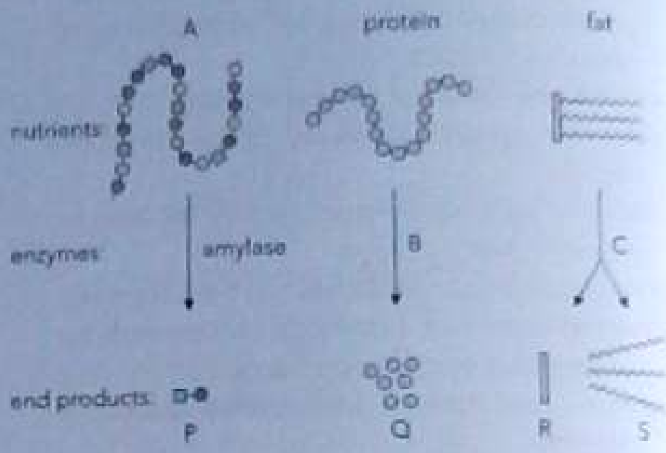
villi – small finger-like structures on the surface of a membrane such as the inner lining of the small intestine (singular: villus)

Revision questions

1. The last portion of the small intestine is called the:
   - A duodenum
   - B rectum
   - C jejunum
   - D ileum (2)
2. The substance that emulsifies fats.
   - A enzyme
   - B lipase
   - C gastric juice
   - D bile (2)
3. The drawing shows some of the organs in the human abdomen.



   a) Assign labels to the organs A, B, C, D and E. (5)
   b) Describe two things that happen to food in the digestive system. (2)
   c) Use the letters from the diagram to show where:
      i) hydrochloric acid is produced
      ii) absorption of water occurs
      iii) mechanical digestion occurs
      iv) chemical digestion occurs. (4)
4. Explain the difference between mechanical and chemical digestion. (4)
5. Why is it important to digest and absorb food into the body? (2)
6. The diagram below shows the digestion of nutrients in the digestive system.



   a) Identify nutrient A (1)
   b) Name enzymes B and C. (2)
   c) What are the end products P, Q, R and S? (4)
   d) Explain why it is necessary to break |down nutrient molecules into single units during digestion. (2)

TOTAL: 30

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Unit 4 Human respiration

Objectives

- Point out the difference between inhaled and exhaled air.
- Describe the role of the alveoli in gaseous exchange inside the lungs.
- Explain how the alveoli is adapted for gaseous exchange inside the lungs.

Introduction

Your body works every moment of the day. Your chest contracts and expands to move air in and out all the time. The **alveoli** inside the lungs exchange gases. Oxygen is transported by the blood to the whole body where it is used for cellular respiration, the process by which cells obtain energy for life processes. During cellular respiration, your cells produce carbon dioxide and this gas is carried to the lungs to be **expelled**. Cellular respiration is a chemical process occurring inside cells in which glucose is used to release energy. This only happens in the presence of oxygen. All functions and activities taking place inside your body require energy.

Percentage composition of inhaled and exhaled air

Breathing enables us to bring in oxygen and to get rid of carbon dioxide. Air passes through the nose or mouth into the trachea. From the trachea it travels into the bronchi into the lungs, through the bronchioles and into the air sacs made up of alveoli. The air we inhale contains more oxygen and less carbon dioxide than the air we **exhale**. The table below shows the gaseous content of inhaled and exhaled air.

Gas	Inhaled air (%)	Exhaled air (%)
Oxygen	21	16
Carbon dioxide	0.03	4.1
Nitrogen	78	78
Water **vapour**	a small percentage (although variable)	a larger percentage

Experiment 4.1

Aim: To investigate the difference in the levels of carbon dioxide in inhaled and exhaled air

Materials: two large boiling tubes, limewater or bicarbonate indicator, glass tubing, two rubber bungs

Procedure

1. Fit two boiling tubes, A and B, with rubber bungs and glass tubing as shown in Figure 4.1.

2. Place equal volumes of limewater or bicarbonate indicator in each tube.
3. Place the mouthpiece in the mouth and breathe gently in and out through the apparatus.

Results

1. What happens immediately in the boiling tubes when breathing begins (before any colour change takes place)?
2. How do you explain your observation?
3. What colour change takes place in the limewater or bicarbonate indicator inside the tubes?
4. What can you conclude about inhaled and exhaled air from your observations?
5. What are the functions of boiling tubes A and B?

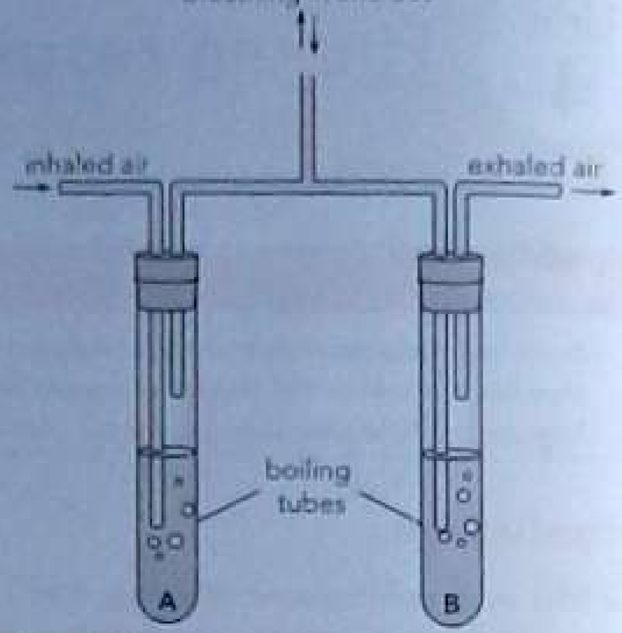


Figure 4.1 A respirometer

Experiment 4.2

Aim: How much air can you breathe in?

Materials: large basin, graduated bell jar, small beakers, tube, water

Procedure

Use the diagram shown in Figure 4.2, to assist you with the procedure.

1. Fill a basin with water. Lay a graduated bell jar on its side in the basin, so that the bell jar fills up with water. Then place the bell jar in an upright position on supports (up-turned beakers). Insert a bent tube under the rim of the bell jar as shown in Fig. 4.2

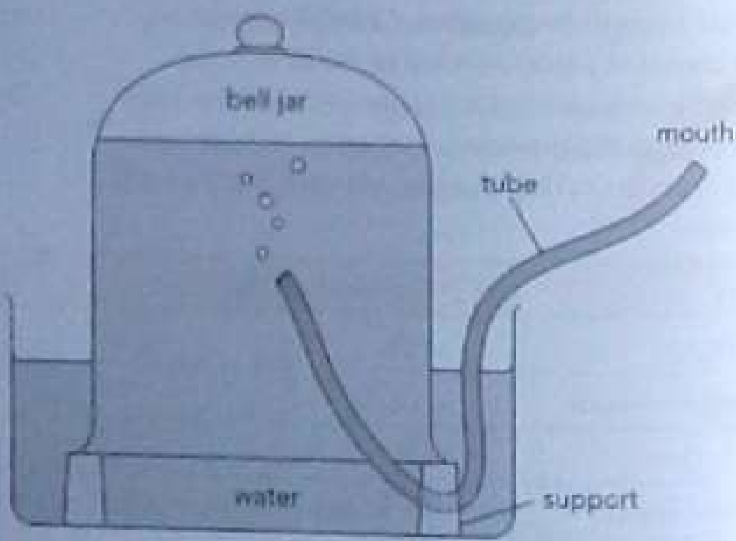


Figure 4.2 Apparatus for measuring vital capacity

2. Take as deep a breath as you can. Then put the end of the bent tube in your mouth and hold your nose. Now breathe out as much as you possibly can. Your exhaled air will displace some of the water from the bell jar. As soon as you have finished breathing out, remove the tube from your mouth.
3. From the scale on the side of the bell jar, read off the volume of air in litres which you have breathed out. This is called your vital capacity. It is the maximum volume of air which you can take into your lungs.

4. Compare the vital capacities of the students in your class. Try to persuade your teacher to take part too!
5. Tabulate the results, together with other information as shown below, for correlation purposes.

Name	Vital capacity (litres)	Age (years)	Height (m)	Body mass (kg)	Activity group, i.e. very active, active, or inactive

6. Use the apparatus again to find the volume of air which you exhale in a single normal breath when you are not at rest. This is called the tidal volume.

The role of the alveoli in gaseous exchange

There are clusters of tiny air sacs, called the alveoli (singular: alveolus), inside your lungs. Gases move into and out from the alveoli in the **alveolar sacs** (clusters) through the process of diffusion. Each lung contains about 70 to 150 million tiny alveoli, thereby providing an enormous surface area for the diffusion of oxygen and carbon dioxide. Each alveolus is surrounded by a network of **capillaries** allowing the free exchange of gases between the alveolus and the blood.

The air you breathe in and that passes into the alveoli has a higher concentration of oxygen than the blood in the surrounding **pulmonary** capillaries. Oxygen dissolves in the moist lining of the alveolus. It then diffuses across the alveolus wall and the wall of the capillaries to combine with the haemoglobin in the red blood cells, forming **oxyhaemoglobin**. Blood arriving from the body cells at the alveolus is rich in carbon dioxide. The concentration of carbon dioxide in the blood is greater than in the air of the alveolus, so carbon dioxide diffuses out of the blood into the alveolus. The air sacs always contain some air, even when we breathe out as hard as we can. If there were no air inside the air sacs, their walls would cave in and collapse. The gaseous exchange surface would then be so reduced that we would **asphyxiate**.

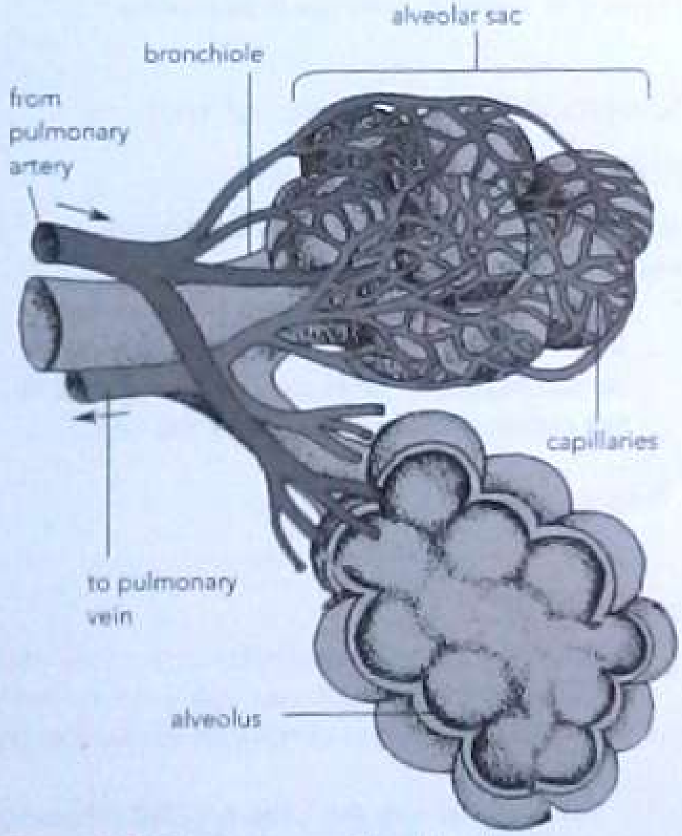


Figure 4.3 The structure of the alveoli

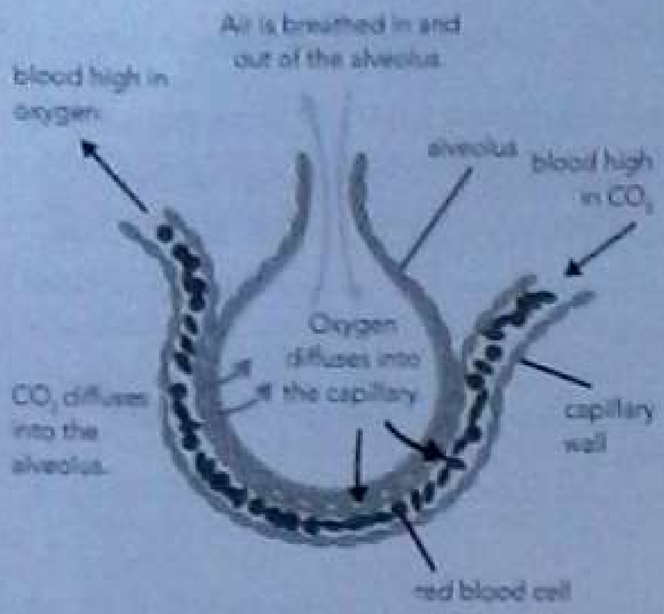


Figure 4.4 Gaseous exchange in an alveolus

Structural adaptations of the alveolus for its function

Alveoli have the following structural features to ensure efficient gaseous exchange:

- There are millions of the tiny alveoli in the lungs to maximise the surface area that can receive oxygen to go to the cells and get rid of the carbon dioxide produced by the cells.
- Each alveolus has a thin wall to allow gases to diffuse between the alveoli and blood quickly.
- Within each alveolus there is a layer of moisture in which gases dissolve to accelerate the process.
- A network of capillaries around the alveolus makes the free exchange of gases between the alveolus and the blood possible.

Project

Work in pairs and create a poster of the airways in the human respiratory system. You have to show the path air takes from the moment you breathe in to the moment it reaches an alveolus in the lungs. You have to indicate the correct names for the different parts of the body through which air moves and you have show how the lungs fit in the chest cavity. Your poster must have a heading and at least ten labels.

You will be evaluated as follows:

Poster

1.	Heading	(1)
2.	Correctness of labels	(10)
3.	Neatness	(2)
4.	Display	(2)
		TOTAL: 15

Summary

- Breathing is the process of taking air into the body and expelling it.
- The composition of the air that is taken into the lungs changes before it is exhaled.
- Oxygen and carbon dioxide are exchanged between the alveoli and blood through the process of diffusion.
- Taking in air into the lungs is called inhalation.
- Oxygen is the gas in inhaled air the body will use in energy production.
- The oxygen from inhaled air diffuses from the alveoli into the blood stream and is taken to all body cells.
- Exhaled air contains more carbon dioxide and less oxygen than inhaled air.
- The carbon dioxide that is released from the cells into the bloodstream diffuses into the alveoli for exhalation.
- The alveoli are the centre of gaseous exchange.
- The alveoli have many structural features to make gaseous exchange happen quickly and easily.
- The alveoli provide a large surface area for the exchange of gases to take place; they have thin walls, are moist and surrounded by an extensive capillary network.

Glossary

alveolar sac – a cluster of alveoli

alveoli – tiny air sacs in the lungs allowing the exchange of gases to and from the bloodstream (singular: alveolus)

asphyxiate – to die from a lack of oxygen and an excess of carbon dioxide in the blood (also to suffocate)

breathing – the process in which the lungs pull in air and expel it

capillary – a thin-walled blood vessel connecting the arteries and the veins

exhale – to breathe out from the lungs

expel – to force out

haemoglobin – red oxygen-carrying pigment in red blood cells

inhale – to breathe in to the lungs

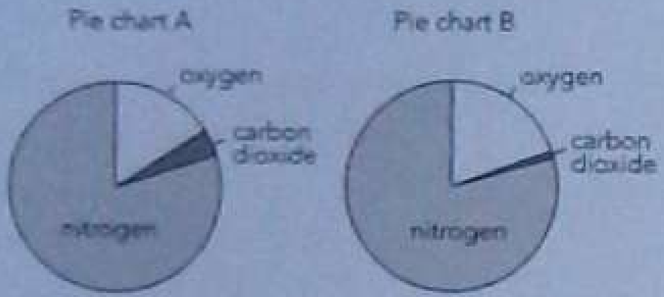
oxyhaemoglobin – the bright red substance formed when haemoglobin combines with oxygen

pulmonary – of the lungs or to do with the lungs

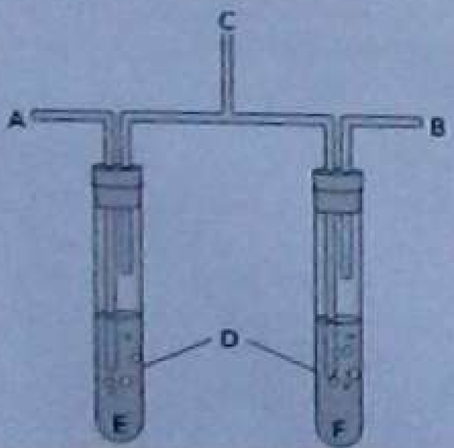
vapour – moisture contained in air or in a gas

Revision questions

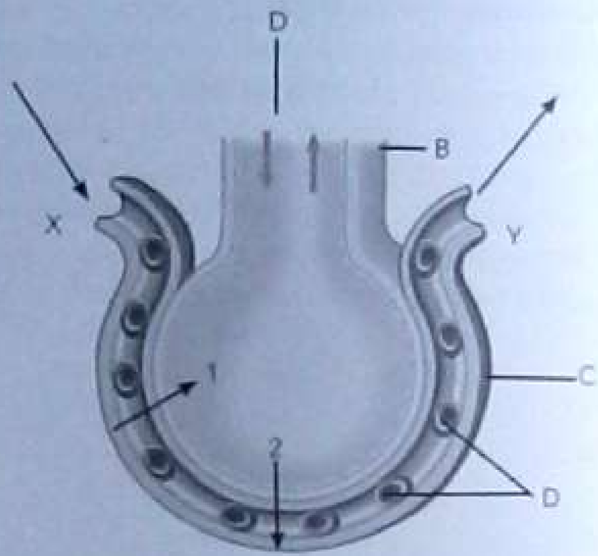
1. Choose the process that produces energy:
   A diffusion
   B inhale
   C cellular respiration
   D diffusion (2)
2. The process of moving air into the body and out from the body is called...
   A osmosis
   B breathing
   C diffusion
   D exhale (2)
3. The two pie charts below show the composition of inhaled and exhaled air:



   a) Identify the pie chart (A or B) representing inhaled air. Give a reason for your answer. (2)
   b) Identify the pie chart (A or B) representing exhaled air. Give a reason for your answer. (2)
   c) Explain why there is no change in the volume of nitrogen we breathe in and out. (1)
4. A learner set up the following apparatus in class:



   a) What is the aim of this experiment? (2)
   b) Identify the indicator labelled D. (1)
   c) Where does the air enter a tube from the atmosphere (A, B or C)? (1)
   d) Where do you put your mouth (A, B or C)? (1)
   d) What happens to the indicator in the test tubes? Explain why this occurs. (2)
5. Study the diagram of an alveolus below and answer the questions that follow:



   a) Identify parts B, C and D. (3)
   b) Name and describe the processes represented by arrows 1 and 2. (4)
   c) Which area (X or Y) in the capillary has the highest carbon dioxide concentration? Give a reason for your answer. (2)
   d) Identify the gases represented by 1 and 2. (2)
   e) Outline two ways in which the alveolus is adapted for efficient gaseous exchange. (4)
   f) Describe how gaseous exchange occurs in the alveoli. (4)

TOTAL: 35

Unit 5 Transport systems in plants

Objectives

- Explain the process of transpiration in plants.
- State the factors affecting the rate of transpiration in plants.
- Measure the rate of transpiration in a plant.
- Outline the importance of transpiration for plants.
- Explain the terms plasmolysis and turgidity.
- Describe the effects of water loss and water gain in plant cells.

Introduction

The movement of water and mineral salts inside a plant happens through two main processes: diffusion and osmosis. Diffusion is the movement of molecules from a region where they are in a higher concentration to where they are less concentrated. This is shown in Figure 5.1 below:

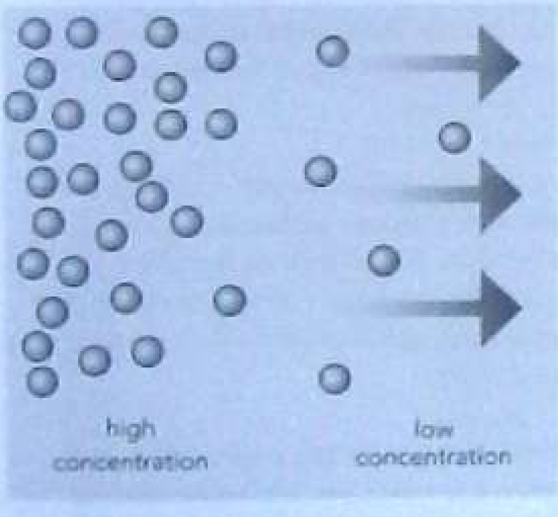


Figure 5.1 The diffusion of molecules

Osmosis happens, however, when water molecules (not a dissolved substance) moves from where the water molecules are in a higher concentration across a semi-permeable membrane to where the molecules are in a lower concentration as shown in Figure 5.2:

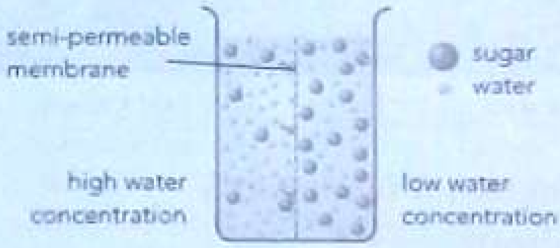


Figure 5.2 The osmosis of water

The difference in concentration of a substance over distance is called its **concentration gradient**. There exists, for example, a concentration gradient for water between the soil and the leaves of a plant. This concentration gradient causes water to move from the roots up to the leaves.

Transpiration in plants

Transpiration in plants is the loss of water vapour from the leaves to the environment. The water and mineral salts the roots absorb are carried by the xylem to other parts of the plant, including to the leaves. Here, due to the heat of the Sun, water changes from a liquid to a gas through evaporation. The water vapour diffuses through the large air spaces between the mesophyll cells to the stomata. From here, the water vapour diffuses out into the open air.

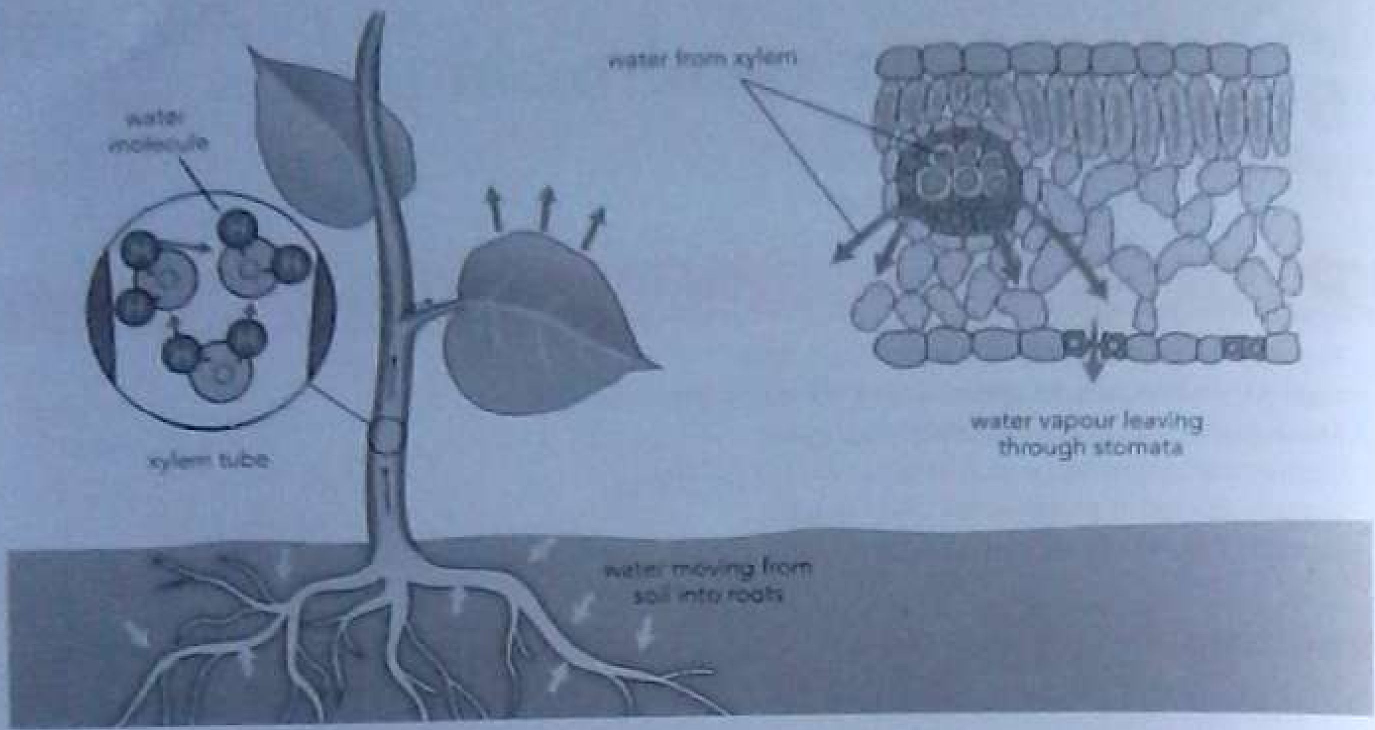


Figure 5.3 The process of transpiration

The factors affecting the transpiration rate

Transpiration pulls water up into the plant. Sometimes this pulling force is stronger than at other times and the plant will lose more water than usual. The speed at which a plant loses water is called its **rate of transpiration**. How the rate varies depends on the structure of the plant as well as on the plant's environment. The following external and internal factors have a great effect on the rate of transpiration:

Wind: There is a thin layer of still air around the leaf. Water vapour leaving the stomata diffuses through this layer of unmoving air and is then removed by wind (moving air) into the atmosphere. Wind can alter the rates of transpiration by removing this still layer of water vapour surrounding the leaves. This increases the concentration gradient for water vapour between the leaf spaces and the air so that the rate of transpiration increases too.

Temperature: Heat increases the **kinetic energy** of water molecules so that they move faster. When the air temperature rises, the leaves of plants also become hotter. This increases the rate of evaporation and water vapour diffuses out of the leaf faster.

Humidity: Dry air creates a steep concentration gradient for water vapour between the leaf air spaces and the air. The rate of transpiration increases. Humid air, on the other hand, reduces this concentration gradient and slows transpiration down dramatically.

Surface area: The greater the surface area of a plant's leaves, the more sun exposure there is. More water moves through the leaves and is lost through transpiration. The smaller the leaf surface, the less is the plant's water usage, because less water is lost by transpiration.

Light intensity: In brighter light, the stomata open more and allow more transpiration to take place. Transpiration thus occurs faster during daytime than at night when the stomata are almost closed.

Stomata distribution: Some plants have more stomata than others. More stomata are found on the lower surface of leaves, away from sunlight and wind. Therefore, these stomata will lose less water through transpiration.

All these factors combine to influence how much water is lost by transpiration. A shortage of water leads to wilting and eventually to the death of a plant.

Measuring transpiration in a plant

A **potometer** is a device that can be used to measure the rate at which a leafy shoot draws up water. Since the shoot will draw up water as it loses it by transpiration, you are able to measure the rate of transpiration. Figure 5.4 shows how a basic potometer is set up. There are different types of potometers, but they all have the same basic features. It consists of:

1. A length of capillary tube. A bubble is introduced to the capillary tube. As water is taken up by the plant, the bubble moves. The distance the bubble travels in a given time is determined by the rate of transpiration by the plant.
2. A reservoir. By turning the tap on the reservoir, the position of the bubble can be set at the start of the experiment. Some designs of potometer use a syringe instead of a funnel with a tap.
3. A tube for holding the leafy twig. In Figure 5.4 the shoot is held in place by inserting a rubber stopper in the tube. The hole in the stopper through which the shoot passes must be thoroughly greased with petroleum jelly to keep it airtight.

As the leaves transpire, the plant uses water from the potometer. The air bubble in the water moves along the capillary tube, showing the amount of water the plant uses. The water level in the beaker drops as a result.

To investigate factors influencing the rate of transpiration, a potometer is placed under different atmospheric conditions such as placing the plant in a bright light, placing it near a fan, and placing it in a humid atmosphere. The speed that the bubble moves along the capillary tube under these different atmospheric conditions will indicate the rate of transpiration. Below are two experiments to perform with potometers.

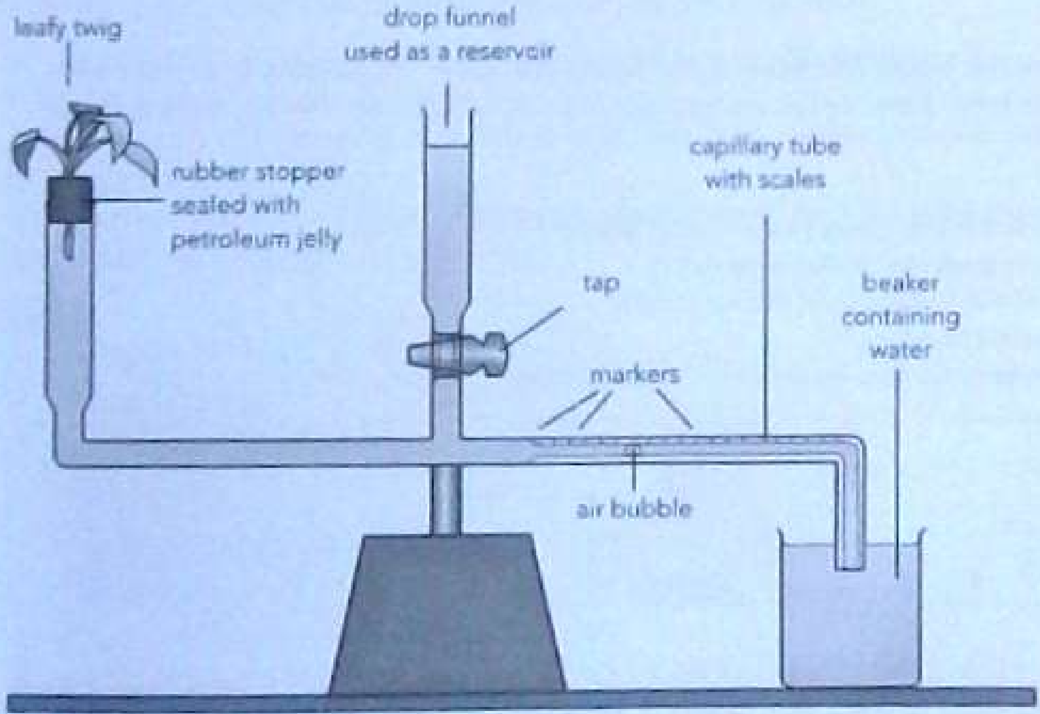


Figure 5.4 A potometer

Experiment 5.1

Aim: To measure transpiration in a plant

Materials: a leafy twig, a potometer, water, beaker, rubber bung, petroleum jelly (Vaseline) to seal connections

Procedure

Note: The apparatus must be completely airtight as bubbles in the system will stop the upward movement of water.

1. Fill a basin with water.
2. Cut a leafy twig under water to prevent any air from entering the xylem. (Air prevents water moving up the xylem to the leaves.)
3. Place the leafy twig into the rubber stopper while still holding it under water.
4. Place the rubber bung into the apparatus as shown in Figure 5.4.
5. Seal all joints and exposed areas with petroleum jelly.
6. There will be air bubbles in the capillary tube. Keep one bubble in the capillary tube by opening the tap of the reservoir. Water moves into the tube to push other bubbles into the beaker.
7. Note the position of the bubble in the tube. The distance the bubble travels shows how much water the stem has taken up.
8. Measure the distance the bubble moves along the capillary tube every 5 minutes for 30 minutes. The movement of the bubble represents the water loss in mℓ by the plant during transpiration. Use the following table to record your results:

Time (minutes)	0	5	10	15	20	25	30
Volume of water (mℓ)							

9. Calculate the rate of transpiration. The volume of water lost by the plant over time indicates the rate of transpiration.

Results

The plant uses water from the potometer, because the leaves transpire. The air bubble in the water moves along the capillary tube, showing the amount of water the plant uses. The water level in the beaker drops as a result.

Questions

1. Why must the stem of the leafy twig be cut under water?
2. What part of the plant does the beaker represent?
3. Why does the level of the water in the beaker drop?
4. Why must the apparatus be sealed?
5. Why must a healthy, leafy branch be used in this experiment?

Experiment 5.2

Aim: To compare the different rates of transpiration of a plant under different atmospheric conditions

Materials: a leafy twig cut at an angle under water, calibrated tubing, clear plastic tubing, petroleum jelly to seal, a plastic bag, rubber band, fan, stop watch, a lamp

Procedure

1. Set up a potometer as shown in Figure 5.5. You will notice that this is a different model to the potometer shown before.
2. Place the potometer on a desk at room temperature. This will be the control of your experiment.
3. Mark the level of water in the calibrated pipette at the start of the experiment.
4. Measure the water loss every 5 minutes for 30 minutes.
5. **Recalibrate** the apparatus by adding water to the calibrated pipette to the same level as at the start of the experiment.

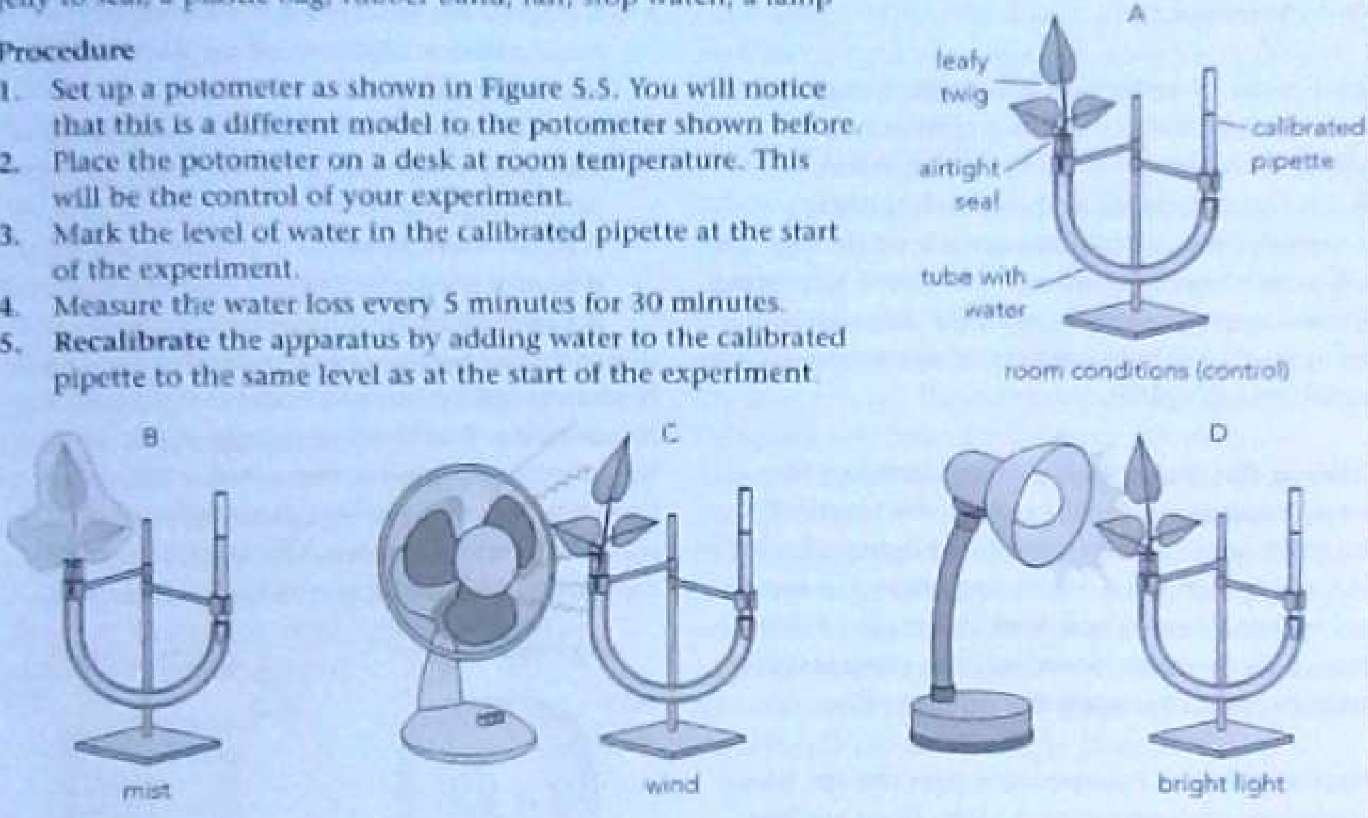


Figure 5.5 Potometers set up for different environmental conditions

6. Cover the leafy twig with a plastic bag to create humid conditions (B).
7. Repeat steps 4 and 5.
8. Now, place a fan in front of the leafy twig. Switch on the fan to create windy conditions (C).
9. Repeat steps 4 and 5.
10. Place a bright light in front of the leafy twig. Switch on the light to increase the light intensity (D).
11. Repeat steps 4 and 5.

Results

1. Copy the table and record your results for the different conditions:

Time (minutes)	0	5	10	15	20	25	30
Volume of water (mℓ) for the control							
Volume of water (mℓ) for humid conditions							
Volume of water (mℓ) for windy conditions							
Volume of water (mℓ) for increased light intensity							

2. Draw a bar graph to illustrate your results.
3. Compare the different rates of transpirations under the different conditions.
4. What can you conclude from the graph with regard to the influence of environmental conditions on the rate of transpiration?

The importance of transpiration for plants

Transpiration plays an important role in the uptake of water and mineral salts, cooling the plant and in photosynthesis.

Movement of water and minerals: Transpiration from the leaf surfaces causes a continuous upward flow of water from the roots via the xylem. Water that is lost is replaced and minerals that are absorbed from the soil are transported through the xylem to where they are needed. This is important, because many plant cells need the minerals as nutrients to produce a variety of substances such as proteins in the plant.

Cooling the plant: Transpiration involves the evaporation of water. The cells in the leaves of the plant are exposed to direct sunlight. When water evaporates due to the Sun's heat, the water loss means a loss of heat from the plant as well. This cools the plant down and this prevents direct sunlight from damaging the delicate cells.

Photosynthesis: Transpiration provides the water needed for photosynthesis to take place and the manufacture of starch in the leaves.

Exercise 5.1

1. Define transpiration.
2. Discuss the process of transpiration.
3. Define the term 'transpiration rate'.
4. What factors affect the rate of transpiration?
5. Explain the importance of transpiration for plants.

Plasmolysis and turgidity

In plants, osmosis takes place when water moves across **semi-permeable** membranes from where it is present in a high concentration to where it is present in a low concentration. In other words, the movement of water in and out of cells occurs through the process of osmosis. The solutions in plants are made up of water and dissolved substances. These solutions can be isotonic, hypertonic or hypotonic when compared to one another. The solutions are compared according to the amount of dissolved substances in the water.

- A **hypotonic solution** contains a lower concentration of dissolved substances than another solution.
- In an **isotonic solution** the concentration of dissolved substances is equal to that of the other solution.
- A **hypertonic solution** contains a higher concentration of dissolved substances than the solution to which it is being compared.

In plants, the movement of water through osmosis is determined by whether cells are surrounded by a solution that is isotonic, hypertonic or hypotonic compared to the cell sap. This is shown in Figure 5.6 where plant cells are placed inside different solutions. The arrows show the movement of water across the cell membrane.

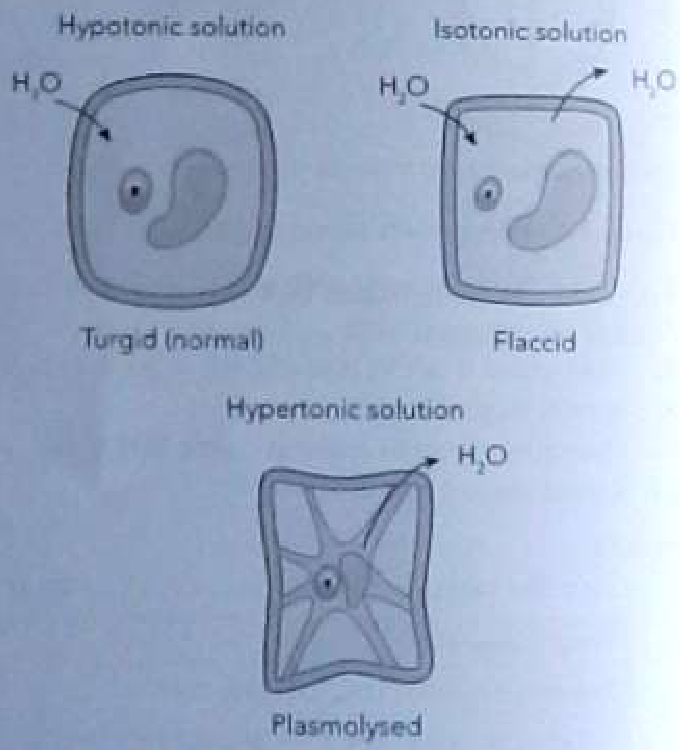


Figure 5.6 Plant cells inside different types of solutions

Hypotonic solution

A solution that is hypotonic when compared to the cell sap inside a cell, is a solution that contains a lower concentration of dissolved substances compared to the cell sap. Water moves by osmosis into the cell and the vacuole where it mixes with the cell sap. The water entering the cell causes it to swell and the cell wall stretches slightly.

The stretched wall exerts an inward pressure on the cell contents. This is called **wall pressure**. When the cell wall cannot stretch any more, it results in a build-up of inner pressure within the cell. This is called **turgor pressure**. The cells are said to be **turgid**. Turgid cells are firm and provide support to the plant to maintain its shape. Turgidity is essential in plant cells to make them keep standing upright. Plant cells that lose much water have less turgor pressure, and tend to become flaccid. Further water loss eventually results in the wilting of the plant.

When a plant cell is turgid, it is swollen, due to a high fluid content. This high fluid content increases the mass of the cell.

Isotonic solution

When a solution is isotonic compared to the cell sap inside a cell, the concentration of dissolved substances in the solution is the same as in the cell sap in the vacuole. In this state, there is equilibrium as the amount of water molecules moving in equals the amount of water molecules moving out.

Hypertonic solution

When a cell is placed inside in a hypertonic solution, the solution is more concentrated than the cell sap. The cell loses water through osmosis. The flow of water out of the cell makes the vacuole and cytoplasm contract. If the cells in a plant lose too much water, they shrink and become **flaccid**. The plant will have less support, the stem no longer remains upright and the leaves wilt. If the outward flow of water from a cell continues, the cell membrane pulls away from the cell wall. This is known as **plasmolysis**. As water is lost through osmosis the vacuole also collapses. As the plant loses water, the contents shrink reducing the cell size and mass compared to when it was turgid. We say the cell has now become plasmolysed.

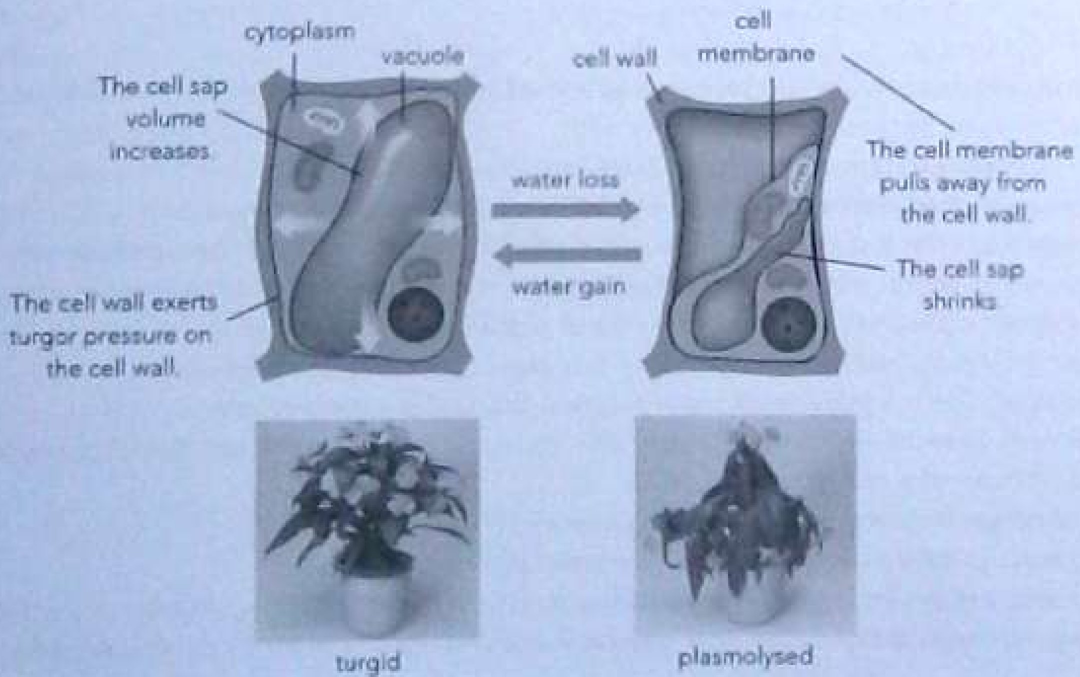


Figure 5.7 A plant with turgid cells and a plant with flaccid cells.

Experiment 5.3

Aim: To demonstrate turgidity and plasmolysis

Work in groups to do this experiment.

Materials: 2 potatoes, 2 dishes containing equal volumes of water, salt or sugar, a scale

Procedure

1. Slice the potatoes lengthwise into several pieces with two flat sliced sides.
2. Weigh the potato pieces and note down their weight.
3. Add about two tablespoons of salt to the water in one of the dishes and stir until the salt is dissolved.
4. Put half of the potato pieces in the dish containing only water.
5. Put the other half of the potato pieces in the dish of salt water.
6. Let the potatoes soak overnight.
7. Compare the appearance and size of the potatoes.
3. Weigh the potato pieces again. Record your results by completing the table you created in Step 2.

Questions

1. Discuss the results you recorded.
2. Explain what would happen if you added more salt to the water.
3. Define the concepts 'osmosis', 'plasmolysed cell' and 'turgid cell'.
4. State the difference between a hypotonic and hypertonic solution.
5. Which dish in the experiment represents a solution that is hypertonic when compared with the potato cells? Give a reason for your answer.
6. Draw a labelled diagram of a potato cell after 24 hours in a concentrated salt solution.

Summary

- Diffusion and osmosis are two processes involved in the movement of water and mineral salts in plants.
- There is a concentration gradient for water between the soil and the leaves of a plant. This concentration gradient causes water to move from the roots to the leaves.
- Transpiration is the loss of water vapour from the leaves of a plant to the environment.
- The process in which water changes from a liquid to water vapour is called evaporation.
- Water vapour diffuses through the stomata of plant leaves into the air.
- Transpiration pulls water up the plant by causing a concentration gradient.
- The speed at which a plant loses water is called the rate of transpiration.
- Factors such as wind, temperature, humidity, light intensity and the number of stomata in the leaves influence the rate of transpiration.
- Water shortage in plants leads to wilting and eventually to death.
- A potometer is used to measure the rate of transpiration in plants.
- Transpiration plays an important role in the uptake of water and mineral salts in a plant, as well as in regulating its temperature and making it possible for the plant to photosynthesise.

- Osmosis is the movement of a solvent, such as water, from a solution with a low concentration across a semi-permeable membrane to a solution with a higher concentration.
- Solutions can either be isotonic, hypertonic or hypotonic when compared to another solution. Each solution is measured according to the amount of substances dissolved in the water.
- A hypotonic solution contains a lower concentration of dissolved substances in comparison to another solution.
- Two solutions are isotonic when they have the same concentration of dissolved substances.
- A solution that is hypertonic when compared to another solution contains a higher concentration of dissolved substances than the other solution.
- The movement of water across cell membranes through the process of osmosis is determined by whether they are inside isotonic, hypertonic or hypotonic solutions.

Glossary

concentration gradient – the difference in concentration of a substance over distance

diffusion – the movement of substances from an area of higher concentration to an area of lower concentration

flaccid – soft and less rigid

hypertonic solution – a solution with a higher concentration of dissolved substances than another

hypotonic solution – a solution with a lower concentration of dissolved substances compared to another

isotonic solution – a solution with a concentration of dissolved substances equal to that of another

kinetic energy – the energy associated with movement

phloem – plant tissue that carries food away from the leaf

plasmolysis – contraction of cell content

potometer – an apparatus used for measuring the rate of transpiration in plants

semi-permeable – allowing the passage of some substances and preventing the passage of others

solvent – a substance in which other substances can dissolve

stomata – pores in the epidermis of a leaf (singular: stoma)

transpiration – loss of water vapour from a plant through the stomata

turgid – swollen, bloated, puffed up or inflated

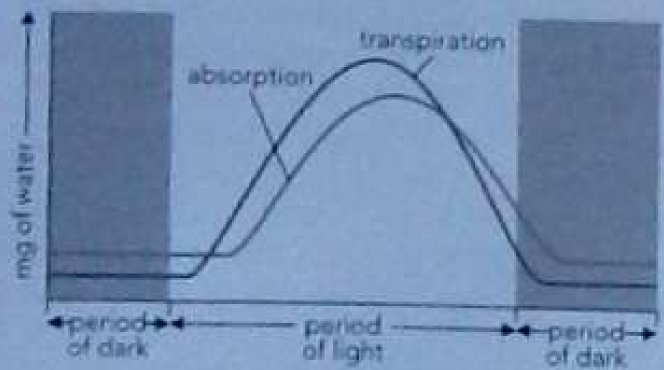
turgor pressure – the pressure of water pushing the plasma membrane against the cell wall of a plant cell

wall pressure – the pressure exerted on the contents of a plant cell by the cell wall

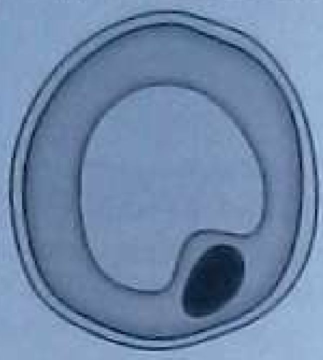
xylem – plant tissue that carries water to the leaf

Revision questions

1. Which of the following conditions is least likely to increase the rate of transpiration in a plant?
   A a rise in temperature
   B an increase in humidity
   C an increase in the movement of air
   D an increase in light intensity. (2)
2. A potometer is an apparatus that can be used to:
   A measure the rate of water uptake in a shoot
   B measure the rate of transpiration in a shoot
   C measure the rate of photosynthesis in a shoot
   D compare rates of transpiration in different conditions (2)
3. Say if the following statements about transpiration are true or false.
   a) It draws water up the stem of a plant.
   b) It draws dissolved salts up the stem of a plant.
   c) It draws food up the stem of a plant.
   d) It has a cooling effect on the leaves of a plant.
   e) It speeds up photosynthesis. (5)
4. The graph below compares the amount of water absorbed by a plant to the amount of water it loses through transpiration.



   a) When does the amount of water absorbed by a plant exceed the amount lost? Explain the reason for your answer. (2)
   b) Explain from the graph when transpiration increases in the plant. (2)
   c) What happens to the rate of absorption as the rate of transpiration increases? Explain why this is so. (2)
   d) When we consider the period of light only, when are the cells of a plant most likely to be turgid or to have high turgor pressure? (1)
5. The figure below shows a plant cell in a strip placed in distilled water.



Explain the changes that the cell will undergo if it were place in a strong salt solution. (4)

TOTAL: 20

Unit 6 Transport systems in humans

Objectives

- List the functions of blood in the human organism.
- List the functions of the different blood components in the human organism.
- Describe the circulatory system in the human organism.

Introduction

Human organisms have a complex transport system. The human body is made up of billions of cells that need a constant supply of nutrients and oxygen in order to survive. Waste substances need to be taken to the kidneys and the skin to be removed from the body. The heart is a pump that ensures the blood, as carrier or transport medium of different substances, moves quickly and under high pressure to all parts of the body. The blood together with the substances it transports is found inside blood vessels.

General functions of blood

Blood performs many functions in the body such as transport of various substances, defence and **homeostasis**.

Transport of various substances

Blood transports important nutrients and materials to and from the cells. It transports nutrients and oxygen to the body cells. Blood transports waste products such as carbon dioxide to the lungs to be expelled and urea to the kidneys and skin for **excretion**. Blood transports white blood cells and antibodies to sites of infection. **Hormones** produced by the glands of the **endocrine system** are transported to target organs in the body.

Defence

White blood cells prevent the spread of infection and disease in the body. White blood cells attack foreign particles and **pathogens** (germs) in the body. They engulf bacteria and waste materials and digest them. White blood cells release antibodies and antitoxins to destroy harmful pathogens. Blood platelets are small, flat discs present in blood and they prevent blood loss by helping the blood to clot quickly.

Homeostasis

The body is exposed to many changes in the external as well as its internal environment. It is important for the body to make continuous adjustments to keep its internal environment stable. The body can function only within certain parameters and needs to maintain the equilibrium, that is, it must maintain **homeostasis**.

The enzymes in blood whose function it is to control various important processes are sensitive to temperature and pH. Enzymes work best at 37 °C and therefore the **blood plasma** maintains this temperature to ensure processes within the body work efficiently. Blood has a pH value of about 7.4. Levels below or above this pH value will affect enzyme activity and overall cellular metabolism. Thus, blood controls the concentration of hydrogen ions in the body to maintain a pH balance.

The levels of water and the concentrations of salt needed by each body cell are also controlled by the blood.

The parts of blood

Blood circulates around your body in the blood vessels. Blood carries many kinds of substances, such as nutrients, gases and wastes to and from all the body cells.

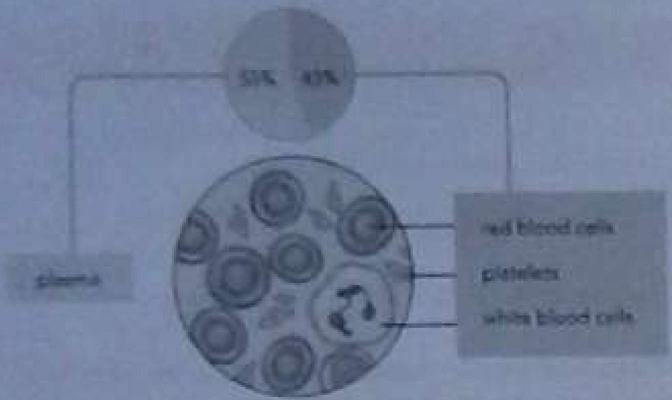


Figure 6.1 The structure of blood

Blood is made up of the following components:

1. **Plasma.** A pale yellow liquid in which the red blood cells, the white blood cells and the platelets float. Blood plasma transports nutrients, waste products, blood proteins, dissolved gases and antibodies. Plasma also distributes body heat to assists in regulating your body temperature.
2. **Red blood cells.** Red blood cells are produced by the red bone marrow of ribs, the sternum, vertebrae, skull and long bones. They are very small biconcave discs that have no nucleus. Their biconcave shape increases their surface area so to absorb oxygen more rapidly. They are enclosed in a thin elastic membrane that can bend when they travel in very thin capillaries. They contain a red pigment called haemoglobin that combines with oxygen to form oxyhaemoglobin that is taken to all the cells. They have a life span of about 120 days after which they are broken down in the spleen and the liver. There are about 5 million of them per mm^3 of blood. Red blood cells also help to transport carbon dioxide to the lungs and to maintain the pH balance of your blood.
3. **White blood cells.** White blood cells are much larger than red blood cells, although they vary in size. They are irregular in shape, colourless and have a big nucleus. They have the ability to leave the blood vessels, enabling them to invade diseased tissues. There are about 5000 to 9000 per mm^3 of blood. White blood cells are formed in the spleen, tonsils, lymph glands and red bone marrow. White blood cells are grouped according whether their cytoplasm is granular or agranular. Granular white blood cells have a nucleus suspended in granular cytoplasm. They are irregular in shape and display amoeboid movement. They protect the body against harmful organisms. Agranular white blood cells have round or kidney-shaped nuclei and cytoplasm without granules. There are two types, namely lymphocytes and monocytes. Lymphocytes produce antibodies against pathogen toxins. Monocytes engulf pathogens.
4. **Platelets.** Platelets are not complete cells but cytoplasmic cell fragments that have no nucleus. They stick together, preventing small leaks in the walls of the blood vessels. When they come into contact with air, they cause the blood to clot. They release a substance called histamine causing the blood vessels to narrow, thereby reducing the loss of blood.

Exercise 6.1

1. What is blood?
2. What components make up blood?
3. What are the functions of the components of blood?
4. How does blood maintain homeostasis in the body?

The circulatory system

Blood forms part of a bigger system in the body. As you have learnt in previous forms, this system is called the circulatory system.

The main structures of the circulatory system are the heart, arteries, veins, capillaries and blood. Your heart pumps blood through all your blood vessels. Your circulatory system carries substances in blood vessels to and from the different parts of the body. The body needs a constant supply of oxygen and food to survive and waste must be removed. Blood carries oxygen and food to the cells and carbon dioxide and other waste products away.

Heart

The heart is a muscular organ found in the centre of your chest between the lungs, but slightly tilted to the left. It is about the size of your fist and protected by the breastbone. The muscle of the heart is called **cardiac** muscle. Your heart beats day and night to keep the blood moving around your circulatory system.

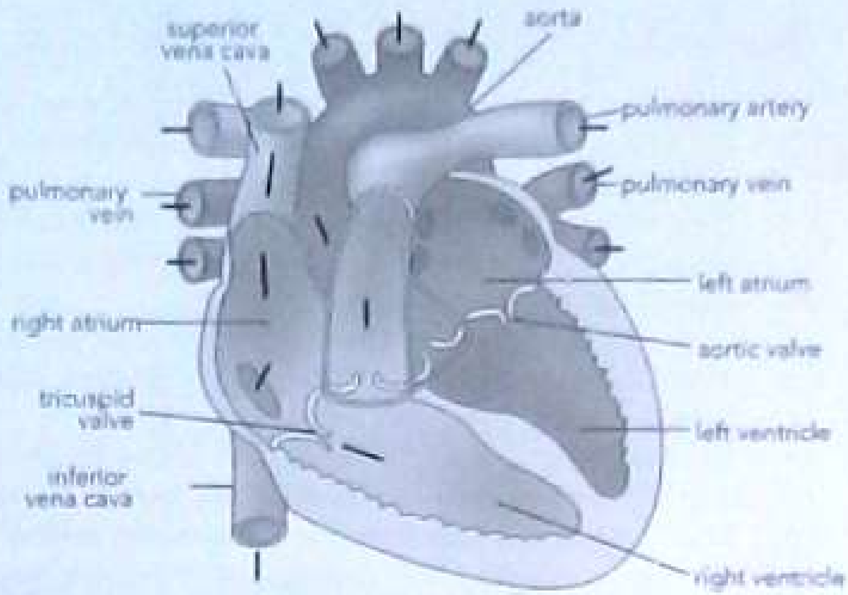


Figure 6.2 The structure the heart

Arteries

Arteries carry oxygen-rich blood away from your heart to all parts of your body. They are found very deep in the body tissue. Blood is carried under high pressure, because of the heart's strong contractions. The arteries have thick muscular walls surrounding a small **cavity**.

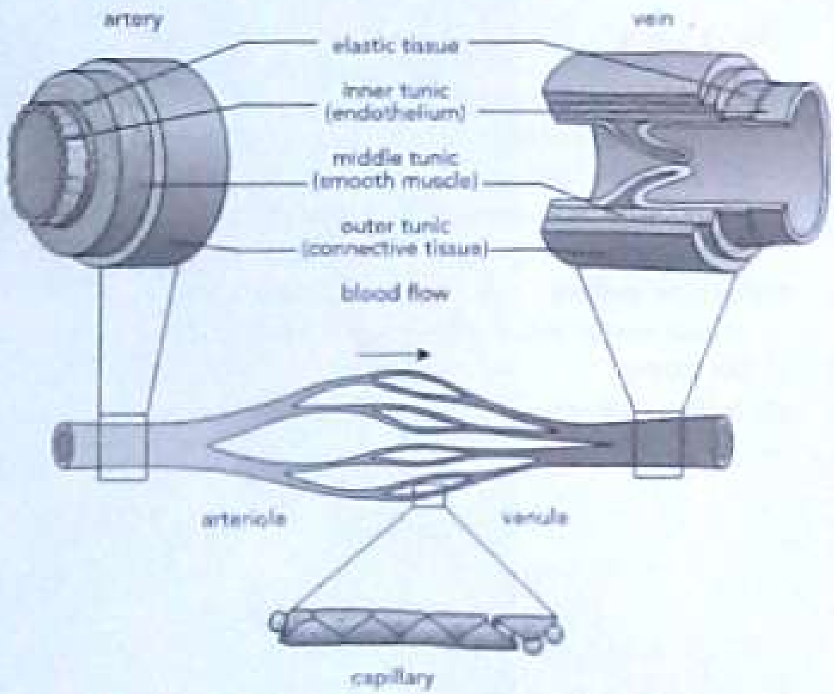


Figure 6.3 The structure of an artery, vein and capillary

Veins

Veins carry blood containing high concentrations of carbon dioxide back to your heart. Veins are found closer to the surface of the body than the arteries. Veins carry blood under low pressure to the heart and they have a thin elastic wall surrounding a large cavity that collapses when it is empty. **Valves** prevent the blood from flowing backwards, forcing the flow in one direction only.

Capillaries

Capillaries are tiny vessels that link the arteries to the veins. They reach every part of the body. Their walls are one layer thick and they allow gases to diffuse through the capillary walls. Oxygen and nutrients diffuse out of the capillaries and carbon dioxide and waste diffuse into the capillaries to be taken away.

Exercise 6.2

1. What is the circulatory system?
2. What components make up the circulatory system?
3. What are the functions of the different components of the circulatory system?

Summary

- Human organisms have a complex transport system.
- The heart pumps the blood so that it moves rapidly and under high pressure to the different parts of the body.
- The blood, the transport medium for many substances, flows inside blood vessels.
- Blood performs many functions in the body: it transports various substances, defends the body and ensures homeostasis.
- White blood cells prevent the spread of infection and disease in the body.
- Blood platelets are small, flat discs present in blood plasma and they prevent blood loss by helping blood to clot.
- Blood circulates around your body in the blood vessels. Blood carries many kinds of substances, such as nutrients, gases and wastes to and from the body cells.
- Blood is made up of the following components: plasma, red blood cells, white blood cells and platelets.
- The main structures of the circulatory system are the heart, arteries, veins, capillaries and the blood.

Glossary

blood plasma – the clear yellowish fluid in which the red blood cells, the white blood cells and the platelets float

cavity – a hollow, for example, inside the arteries or the veins

endocrine system – the system of glands that produces and secretes hormones directly into the blood

excretion – the expulsion of waste materials

homeostasis – the maintenance of normal internal conditions in a cell or an organism by self-regulatory mechanisms

pathogen – an agent that causes a disease

pH – a measure of the concentration of hydrogen ions in a solution, or an indication of acidity or alkalinity according to the pH scale

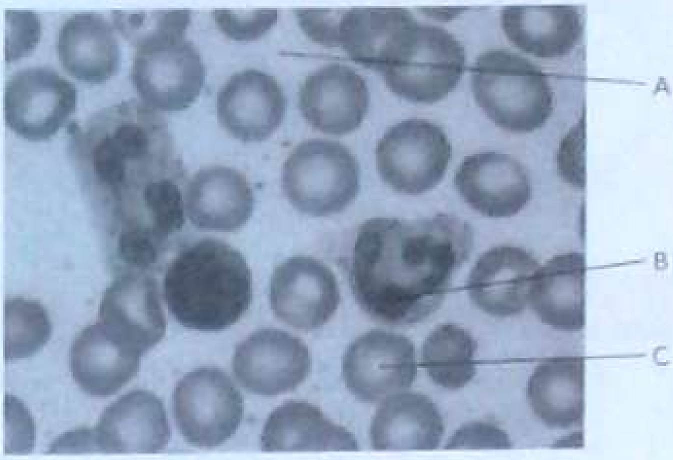
valve – in this context, the flaps of tissue in the circulatory system allowing blood flow only in one direction

Revision questions

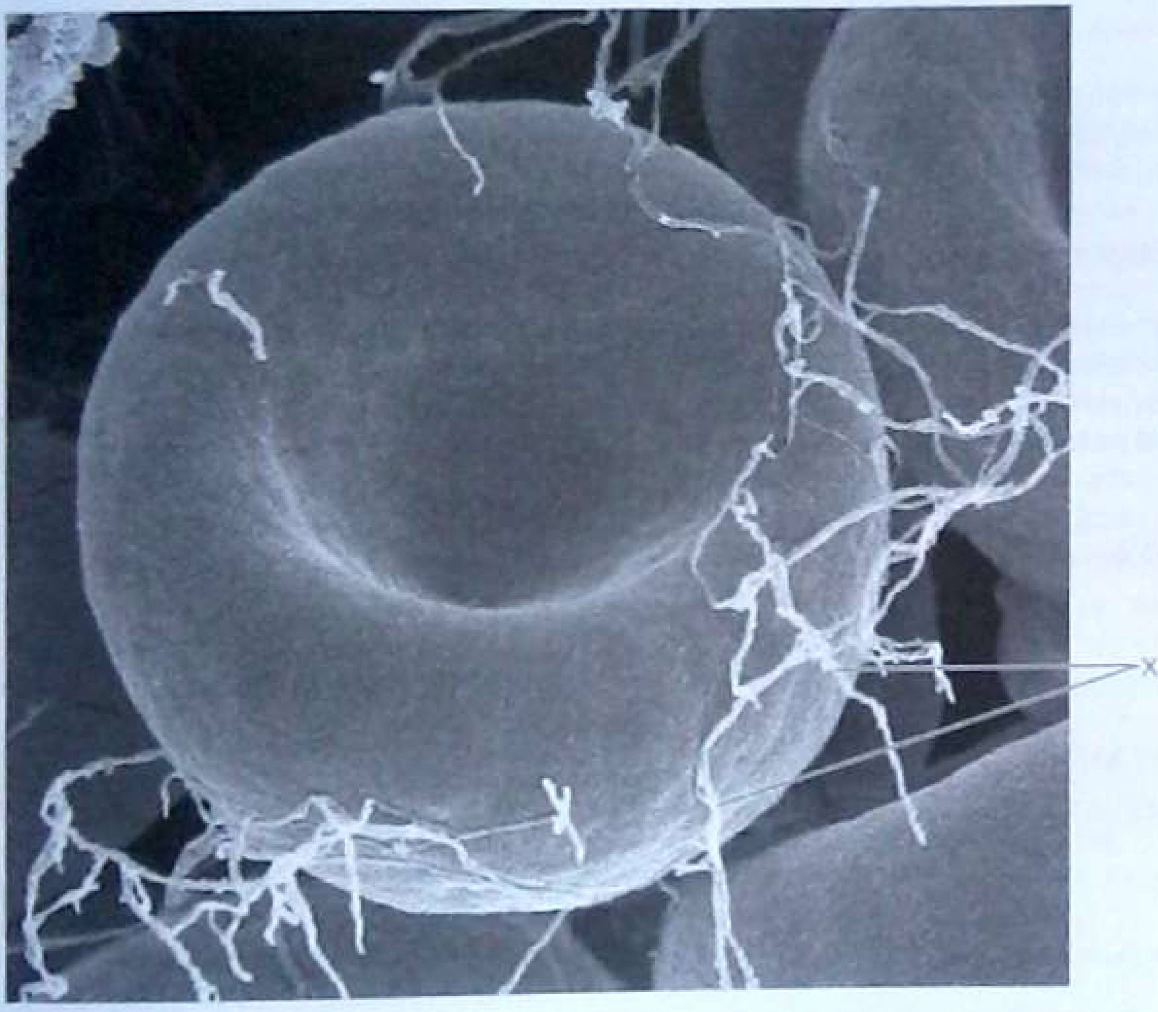
1. The cells protecting the body against disease by engulfing bacteria and destroying them are called:
   - A platelets
   - B anti-retroviral
   - C red blood cells
   - D white blood cells (2)

2. The name of the substance that regulates heat in the blood.
   - A platelets
   - B plasma
   - C red blood cells
   - D enzymes (2)

3. The diagram to the right shows different cells found in blood tissue. Study it carefully and answer the questions that follow.
   a) Identify structures A, B and C. (3)
   b) Give one function of structure B. (1)
   c) Give two ways in which cell C is adapted for its function. (4)



4. Humans belong to one of four blood groups: A, B, AB and O. In a recent survey, 40% were type A; 10% were type B; 5% were type AB; 45% were type O.
   Display this information in a pie chart. (6)
5. The photograph shows a red blood cell in a blood clot that has formed. The fibres labelled X are produced in the early stages of the clotting process.



   a) What component of blood is mainly responsible for the formation of these fibres when blood clots? (1)
   b) The average diameter of a real red blood cell is 0.008 mm. On the photograph, the diameter of the red blood cell is 100 mm. Work out the magnification of the photograph by applying the formula below:

      diameter on photograph = real diameter × magnification (1)

TOTAL: 20

Unit 7 Plant reproduction

Objectives

- Explain the structures of wind and insect pollinated flowers.
- Describe the process of germination.
- Investigate what conditions are necessary for germination.
- Calculate germination rates.

Introduction

Flowers are the reproductive organs of a plant. The structure of a typical flower ensures that **pollination** and **fertilisation** occurs.

The structure of a flower

Flowers are arranged in four whorls, which are attached to a wide base called the receptacle at the end of the flower stalk. The outer whorl is made up of sepals that protect the flower bud. The petals are usually colourful and attract insect pollinators. The two inside whorls contain the male and female structures of the flower, which produce the sex cells.

Figure 7.1 The parts of a flower

The male structure, the **stamen**, is formed by the **anther** and filament. The anther produces **pollen grains** with male sex cells. The anther is held up by the filament. The female structure, or **pistil**, consists of the **stigma**, style and **ovary**. The stigma is used to receive pollen, while the style joins the stigma to the ovary. The ovary produces structures called ovules. Each ovule holds one female sex cell.

Pollination

You have learnt in previous forms that flowers can only form **seeds** and **fruit** when they have been pollinated. Pollination is the transfer of pollen grains from the anther to the receptive stigma of the same **species**. The purpose of pollination is to allow **fertilisation** to occur. Fertilisation is the fusion of male and female gametes or sex cells. The male **gamete** is produced in the anther and the female gamete is found in the ovule in the ovary. Pollen is transferred from one flower to the next in different ways. It can be carried by insects, birds, small mammals, wind or water. For example, when bees visit flowers looking for food, pollen from the anthers sticks to their bodies. When they visit another flower, the pollen can stick to the stigma of this flower. If the flower is of the same species, pollination takes place.

There are two types of pollination. When pollen is transferred to the stigma of the same flower, it is called **self pollination**. When the pollen is carried to the stigma of another flower of the same species, **cross pollination** takes place. A **pollinator** is a carrier of pollen from the anther to the stigma. Insects can thus act as pollinators.

During pollination pollen grains land on the stigma of a flower of the same species. A mature pollen grain contains two male sex cells. The pollen grain bursts open and grows a pollen tube. Two male sex cells are inside the pollen tube. The pollen tube grows down the neck of the style into an ovule where one male sex cell fuses with the female egg cell. The other male sex cell fuses with two cells in the embryo sac of the ovule to form the endosperm so that we call this process **double fertilisation**. The endosperm is filled with starch that provides food for the developing seed. After fertilisation, the ovary enlarges and develops into a fruit. The seeds are contained inside the fruit. The fruit protects the seeds until they ripen. Many parts of the flower are no longer needed. The sepals, petals and stamens thus dry up and fall off.

Wind as an agent of pollination

Pollen is carried from one flower to another by the wind. Plants such as grasses and mealies rely on wind to blow their pollen from one flower to the stigma of another. These plants produce large amounts of very light and dry pollen, so that it is easily blown away. The stigmas are large and feathery, so that they catch any pollen grains blowing past. Stigmas are also sticky to trap the pollen.

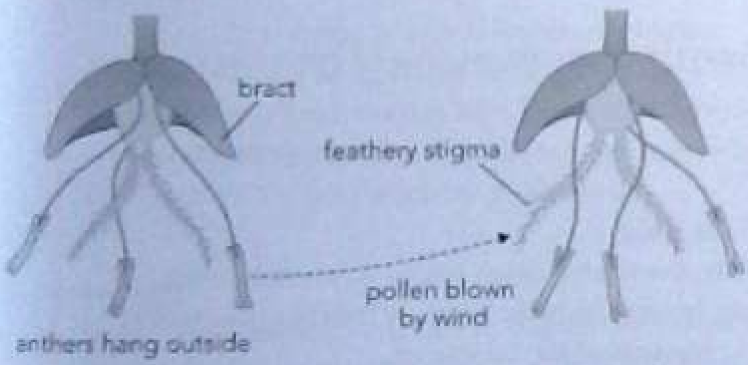


Figure 7.2 Plants pollinated by the wind have feathery anthers and stigmas hanging outside the flower.

Insect as an agent of pollination

Many plants rely on insects to transfer pollen from the anther of one flower to the stigma of another flower. Insects such as bees, butterflies, moths, beetles and even flies are a few examples of insects that pollinate flowers.

Figure 7.3 Our national flower, the flame lily, is one of the insect pollinated flowers.

Flowers that are pollinated in this way have special adaptations such as large colourful petals or they have a definite scent or perfume to attract insects. Some flowers produce sweet **nectar** to attract insects, because insects use nectar for food. Anthers have sticky pollen grains so they can easily stick to the insect's body when it brushes past them to get to the nectar. The stigma is also sticky so that when the insect lands or brushes past it, the pollen grains on the insect's body stick to the stigma.

Exercise 7.1

1. What benefits do flowers get when insects visit them?
2. Why do wind pollinated flowers have long feathery stigmas?
3. Explain why wind pollinated flowers are tiny, not coloured, have no scent and no nectar.
4. Describe how some flowers are adapted to promote insect pollination.

Experiment 7.1

Aim: To investigate the different structures of wind and insect pollinated flowers

Materials: hand lens, bright-coloured flowers, long grass flowers

Procedure

1. Identify which flowers are wind and insect pollinated. Give a reason for your choice.
2. Copy the table into your exercise book and complete it.

Feature	Insect pollinated	Wind pollinated
petals		
scent		
stamens		
stigmas		
pollen		
nectar		

3. Answer the following questions for each flower
   a) Is the flower brightly coloured or not? Explain the purpose of bright colours
   b) Does the flower have a scent? Why is this feature important?
   c) Are the stigmas and anthers inside the flower or hanging outside? Why is this feature important?
   d) Describe the stigmas (small or large and feathery). Explain the purpose of this feature.

Results

1. Wind pollinated plants produce large amounts of very light and dry pollen that can be blown away easily.
2. The stigmas are large, feathery and sticky to trap the pollen.
3. Insect pollinated flowers have large colourful petals, scent and sweet nectar to attract insects.
4. Anthers and stigmas are arranged so that, when an insect lands on them or brushes past them, the pollen grains stick to the insect's body and is transported to the stigma.
5. Draw the different structures of wind and insect pollinated flowers.

The process of germination

Once the seeds have dispersed, they can remain **dormant** for months or even years until the conditions for **germination** and the growth of new plants are right. The seed of a **dicotyledonous plant** has three main parts:

- the seed coat
- the **embryo**
- the **cotyledons**.

The seed coat is a tough protective outer covering. The embryo consists of the young root and the young shoot that will develop into the adult plant later. The cotyledons provide food for the germinating seed which it uses until it is large enough to make its own food.

Germination starts when a seed absorbs water, which causes the seed to swell. The food supply

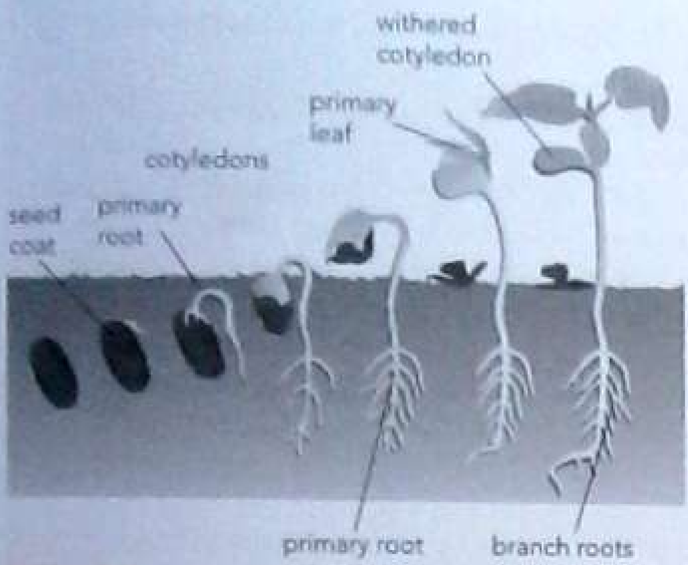


Figure 7.4 Stages in the germination of a bean seed

in the seed is enough to last the seedling until it has grown some roots, a stem above the ground and its first leaves. These leaves then begin to photosynthesise, that is, to provide food for the young growing plant.

In the next experiment, you are going to observe the process of germination closely and record your observations.

Experiment 7.2

Aim: To observe the process of germination

Materials: 10 seeds (bean, mealie, or radish), cotton wool, 2 saucers, a cooldrink bottle, a ruler and fine black permanent marker

Procedure

1. Soak some seeds in a little water overnight.
2. Place the seeds on damp cotton wool on a saucer. Make sure the cotton wool is kept moist throughout the observation period.
3. Observe the germination of the seeds.


Figure 7.5 Measuring the growth of a bean plant

Results

Record your observations every day for two weeks or until the first leaves have emerged. Create a table similar to the one below. You will draw a picture of your seed every day and you will note any changes. (For example, the root tip appeared.)

Day	Diagram of my seed	What changes occurred?
1		
2		
3		

Once the young stem begins to appear measure the height of the plant with a ruler each day as shown.

You will measure and record the height of your plant in a table for 7 to 10 days. Draw a line graph from the entries in your table.

Activity 7.1

Fill in the gaps:

____ starts when a seed absorbs water, which causes the seed to swell. The root starts to grow from the ____. Then a young ____ appears, and its first ____. The food supply in the seed is enough to last the seedling until it has grown some ____, a stem above the ground and the first ____. These leaves then begin to ____, to provide food for the young growing plant.

Moisture, warmth and oxygen

Seeds need water, warmth, oxygen and nutrients to germinate. Water allows the seed to swell up and the embryo to start growing. Oxygen is used so that energy can be released for germination. Up to a certain point, germination improves as temperatures rise.

In the next experiment you will investigate in groups what conditions favour germination.

Experiment 7.3

Aim: To investigate what conditions are needed for germination

Materials: Each group will need five tubes (or beakers), 20 bean or mustard seeds, cotton wool, a rubber bung, plastic wrap, refrigerator or ice, masking tape, petroleum jelly, pyrogallic acid, pens

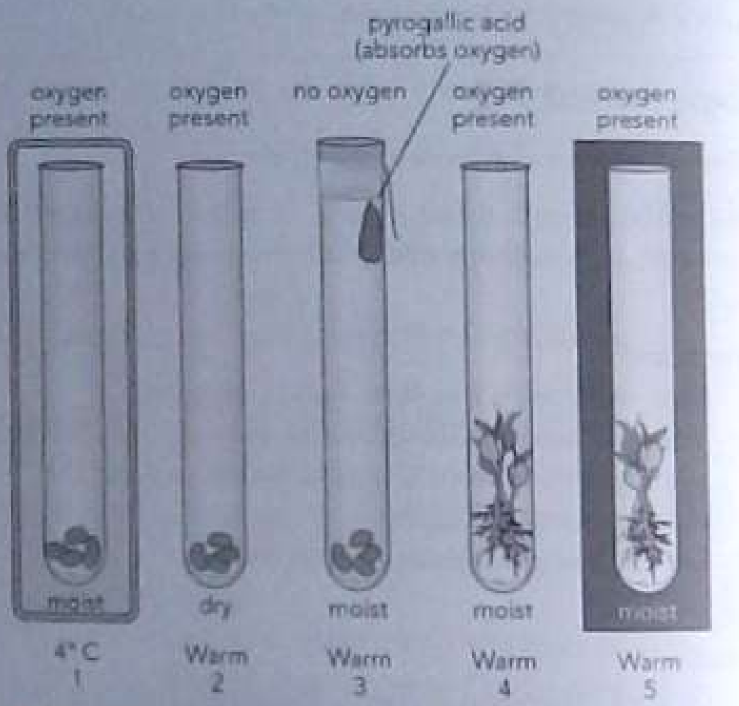


Figure 7.6 Testing the conditions needed for germination

Procedure

1. Separate the bean seeds into 5 groups.
2. Set up apparatus as shown in Figure 7.6.
3. Label the test tubes 1 to 5 using the following key.
   Test tube 1: Water, oxygen and a low temperature. Place test tube 1 in the fridge or put it into a beaker filled with ice for duration of the experiment.
   Test tube 2: No water, but with oxygen and at a warm temperature.
   Test tube 3: Water, no oxygen and at a warm temperature. Add pyrogallic acid to the beaker. Smear petroleum jelly on the rim of the test tube. Put plastic wrap on top so that it completely covers the opening of the tube. Use a rubber band to firmly hold the plastic in place and to keep out oxygen.
   Test tube 4: Water, oxygen and a warm temperature.
   Test tube 5: Water, oxygen, a warm temperature, but no light. Cover the test tube with a black cloth for the duration of the experiment.
4. Place Test tubes 2 to 5 in a warm place for the duration of the experiment (5 to 10 days).
5. Water only Test tubes 1, 3, 4 and 5 every day to keep the cotton wool moist.

6. Draw a table like the example below and record your observations each day:

Day	Test tube 1	Test tube 2	Test tube 3	Test tube 4	Test tube 5
1					
2					
3					
4					
5					

7. For the next 5 to 10 days (the duration of the experiment), observe what happens in each test tube and record it. Record the total number of seeds that have germinated in each test tube should be recorded to correspond to the associated time interval.

Results

Test tube 1: Few seeds germinated.
Test tube 2: No seeds germinated.
Test tube 3: No seeds germinated.
Test tube 4: All seeds germinated.
Test tube 5: Some seeds germinated.

Questions

1. In which test tubes did germination occur?
2. Can you find reasons for what you observed?
3. Is light required for germination? Explain your reasoning.
4. Is oxygen required for germination? Explain.
5. Is water required for germination? Explain.
6. Can seeds germinate under cold conditions? Explain.
7. List the conditions necessary for the germination of a seed.
8. At what point in their development do you think plants must receive light to survive? Explain your answer?

Germination rate

Some seeds remain dormant until conditions are favourable to germinate. Due to various factors, some seeds will germinate while others will never germinate. Farmers sometimes do a germination test to determine the maximum germination potential of the seeds they want to grow. The germination rate is expressed as a percentage. This means an 80 % germination rate shows that 80 out of 100 seeds that are planted will probably germinate. To farmers this information is very important as it could predict the yield of their crop.

Activity 7.2

Work in groups to practise calculating the germination rate (as a percentage) of seeds in groups. Each group will need: radish seeds, paper towel or filter paper, 3 resealable plastic bags, a board and pens. Follow this procedure:

1. Place a piece of folded wet paper towel on the board.
2. Place ten (or multiples of ten) seeds on the wet paper towel. (The more seeds you use, the more reliable your results will be. Using **multiples** of ten makes it easier to calculate percentages.)

3. Place the wet paper towel in a resealable bag.
4. After a few days count how many seeds have sprouted a root and leaves.
5. Use the following formula to calculate the percentage germination rate:

Germination rate

$$= \frac{\text{number of seeds sprouted}}{\text{total number of seeds on board}} \times \frac{100}{1}\%$$

6. Write a report and answer the following questions:
   - What was the germination rate?
   - How would you make your investigation more reliable? What is the independent variable?
   - Identify the dependent variable.
   - Name three factors that should be kept constant to ensure the validity and fairness of the experiment.
   - What impact would a low germination rate have on a farmer who grows vegetables to sells on the local market?

Summary

- Flowers are the reproductive organs of plants.
- Seeds and fruit can only form if flowers have been pollinated.
- Flowers are adapted for specific methods of pollination to take place.
- Insects perform an invaluable service by pollinating some of our food crops.
- Seeds need water, a suitable temperature, as well as oxygen to germinate.
- Determining the maximum germination potential of seeds helps farmers predict the success of their crops.
- The germination rate of seeds is expressed as a percentage.

Glossary

anther – part of the stamen (male part of the flower) producing pollen grains

cotyledon – a structure in the seed filled with starch to provide food for the sprouting seed

dicotyledonous plant – a flowering plant with two cotyledons

dormant – lying inactive, not germinating to produce a new plant

double fertilisation – fertilisation in flowering plants where one male sex cell fuses with the female egg cell and a second male sex cell fuses with two other cells in the embryo sac

embryo – in this context, the beginnings of a new plant inside a seed

fertilisation – the fusion of a male sex cell with a female sex cell

fruit – the fleshy part of the ovary

germination – process in which a seed starts to sprout to develop a new plant

nectar – sugary substance produced by plants to attract insects for pollination

ovary – organ producing female egg cells or ova

pistil – the female part of a flower

pollen grain – a dust-like grain containing the male reproductive cell

pollination – the transfer of pollen from the anther of one flower to the stigma of a flower from the same species

seed – the unit of reproduction produced by flowering plants

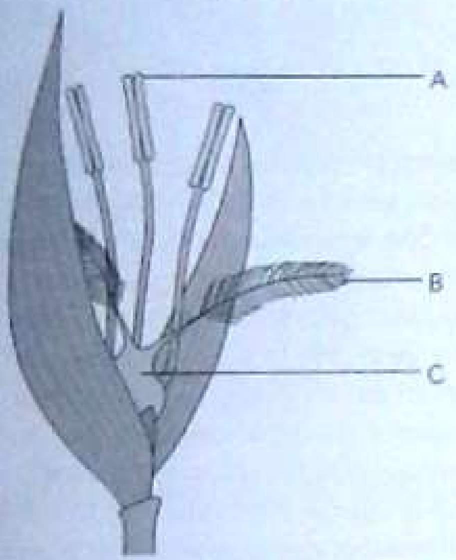
species – group of living organisms sharing the same characteristics and able to breed together

stamen – the male part of a flower

stigma – part of the pistil (female part of the flower) where pollen must land for pollination to take place

Revision questions

1. A group of living organisms looking similar and able to breed with each other is called a ...
   - **A** population
   - **B** species
   - **C** stigma
   - **D** seed (2)
2. The fleshy part of the ovary is called the ...
   - **A** ovule
   - **B** embryo
   - **C** fruit
   - **D** seed (2)
3. Study the following diagram of a flower with no bright colour:



   a) Name the parts of the flower labelled A, B and C and provide their functions. (6)
   b) Is this flower pollinated by insects or by wind? Give two reasons for your answer. (4)
   c) Tabulate three differences between insect and wind pollinated flowers. (6)

TOTAL: 20

Unit 8

Human reproduction

Objectives

- Draw and label the male and female reproductive systems in humans.
- State the functions of the male and female reproductive systems in humans.
- Describe the structure and functions of human sex cells.
- Draw and label the human sex cells.
- Describe the menstrual cycle in human fertility.
- Describe the role of the placenta in human reproduction.
- Identify the substances exchanged in the human placenta.

Introduction

Reproduction is very important in continuing the species by producing offspring. In the female the ovaries produce eggs. In the male the **testes** produce **sperm**. **Fertilisation** (conception) occurs when an egg and sperm fuse.

The structure of the male reproductive system

The main organs in the male reproductive system include the two testes, the sperm duct, the **scrotum** and the penis. The male reproductive organs are specialised to produce sperm and deliver them to the female.

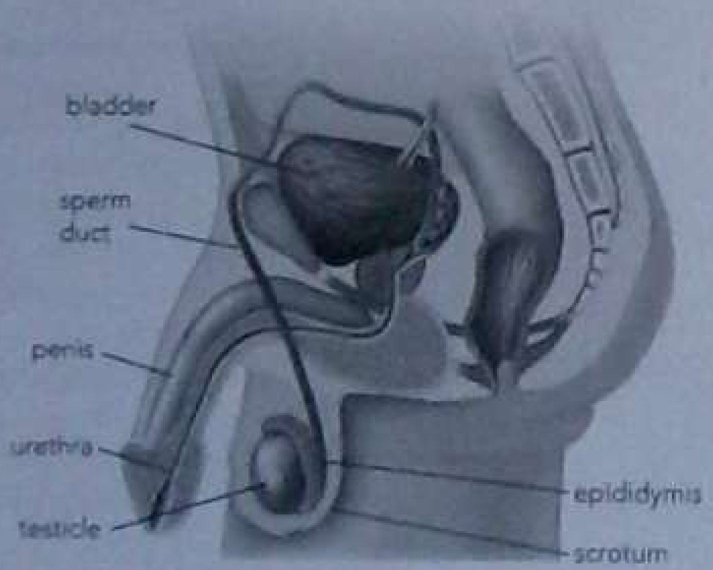


Figure 8.1 The parts of the male reproductive system

The **testes** produce millions of sperm cells each day. The sperm are stored in the epididymis where they mature. The testes also produce a hormone called testosterone that determines the male's secondary sexual characteristics during puberty. The testes are protected in a sack of skin outside the body, called the **scrotum**. To develop, the sperm cells need a lower temperature than normal body temperature. For this reason, the scrotum and testes hang outside the body. This allows the temperature in the scrotum to be lower than in the body. For reproduction to occur the sperm needs to reach the **ovum** in the female. The penis has special tissue which can be filled with blood, to make the penis stiff or erect. The penis needs to be erect to transfer sperm cells into the female's **vagina** during intercourse. The tip of the penis is slightly enlarged and covered by a loose skin called the foreskin. The foreskin covers and protects the head of the penis.

Sperm travels from the testes into the sperm ducts. As the sperm travels, glands release fluid into the sperm duct. This fluid contains food that provides energy to help the sperm swim. The mixture of fluid and sperm is called **semen**. The sperm ducts join the **urethra**. The urethra is a tube leading from the bladder through the penis and opens to the outside at its tip. The urethra carries the sperm through the penis to exit the body during **ejaculation**.

Female reproductive organs

The main organs in the female reproductive system include the two ovaries, the two Fallopian tubes, the **uterus** and the vagina. The female reproductive organs are designed to produce female sex cells and to hold and protect the growing embryo that will develop into the **foetus** during pregnancy. The ovaries produce hormones that control the menstrual cycle.

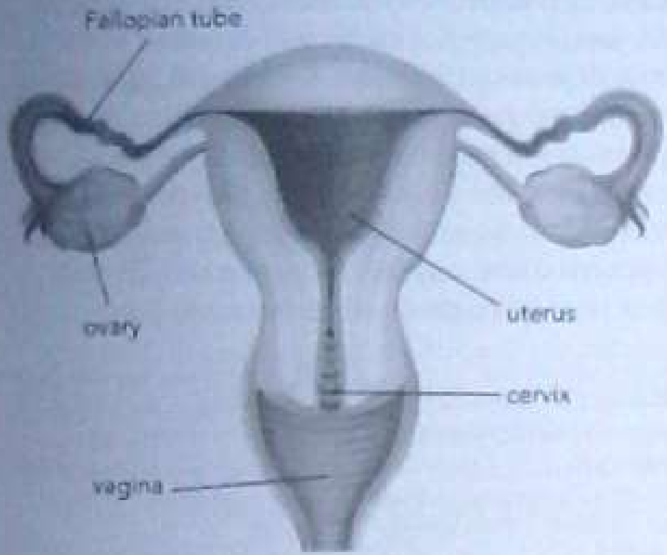


Figure 8.2 The female reproductive organs

The **ovary** contains many egg cells or **ova** (singular ovum). When an ovum is released from the ovary it is carried along the Fallopian tube, towards the uterus. Fertilisation occurs in the Fallopian tube.

The **uterus** is a pear-shaped structure where the fertilised egg is implanted and where the **embryo** develops during pregnancy. It has strong muscular walls and a soft, spongy tissue layer that lines the inner lining of the uterus. This layer is called the **endometrium**. If fertilisation has occurred, the fertilised ovum will implant itself into the endometrium.

At the base of the uterus there is a ring of muscle called the **cervix**.

The cervix leads to the **vagina** and it also produces a fluid it passes into the vagina. The muscular walls of the vagina stretch during childbirth.

Exercise 8.1

1. What is the main function of the male reproductive system?
2. Give the functions of the following:
   a) testes
   b) sperm duct
   c) scrotum
3. Draw a flow diagram of the path of a sperm cell from production to ejaculation.
4. What is the advantage in having the testes held outside the body in the scrotum?
5. Why would the testes move closer to the body when it is cold and further away from the body when it is warm?
6. What is the function of the female reproductive system?
7. Identify the part of the female reproductive system where:
   a) the foetus develops.
   b) the sperm is placed by the penis.
8. List the parts through which the ovum travels.

The structure of the sex cells

Throughout the animal kingdom, the structure of the sperm and ova is similar. The nuclei of the sperm and egg contain chromosomes that carry the genes of either the mother or father. Both the sperm and the egg are single cells each containing a cytoplasm surrounded by a cell membrane and it has a nucleus.

The structure of a sperm cell

Sperm cells are about 10 000 times smaller than the ova. A **sperm** cell has a head, a middle section and a tail. The head contains a nucleus with the **heritable** characteristics from the father. At the tip of the head is a structure containing enzymes and it is called the **acrosome**. The enzymes are used to break down the membrane of the egg so that fertilisation can occur. There are many **mitochondria** (singular: mitochondrion) in the middle section, which provide energy so the sperm can swim towards the ovum.

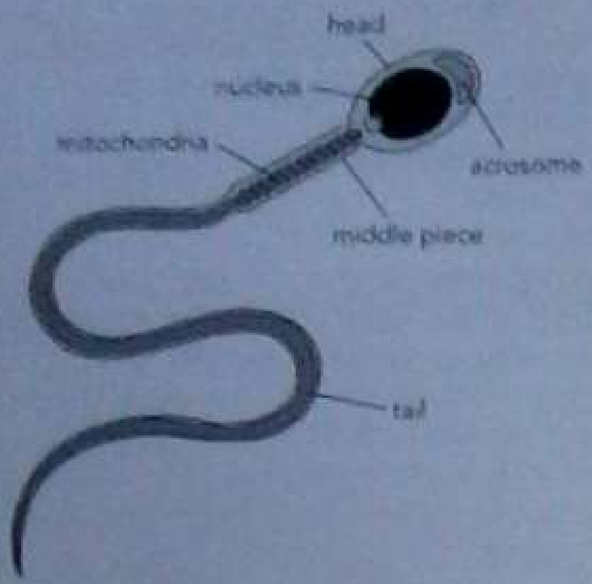


Figure 8.3 The structure of a sperm cell

The structure of an ovum

An ovum has a nucleus, cytoplasm and is surrounded by a cell membrane. The nucleus contains the heritable characteristics from the mother. The cytoplasm stores the food for the embryo to develop and grow. A thick jelly coat covers the cell membrane.

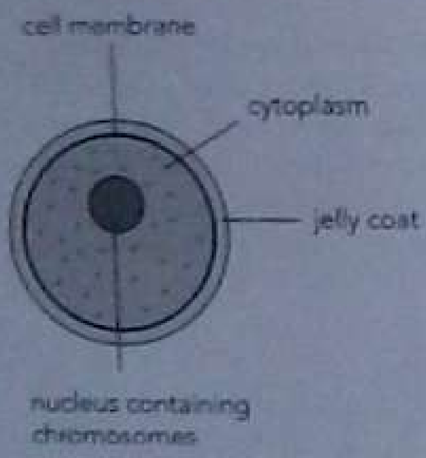


Figure 8.4 The structure of an ovum

Exercise 8.2

1. Draw and label the structure of a sperm cell and an ovum.
2. What is the function of the acrosome?
3. State the function of the mitochondria in the sperm cell.
4. What is the function of the nuclei in the sex cells?

The menstrual cycle

The menstrual cycle is the process that prepares a woman's body for pregnancy. A female is born with thousands of immature ova in her ovaries. When she reaches puberty, these ova begin to mature. The ovum has information about the characteristics of the female that will be passed on to the child, if fertilisation takes place. One ovum is released from an ovary about every 28 days, so that the average menstrual cycle is about 28 days. However, a cycle can be as short as 21 days or as long as 45 days. During puberty females begin to menstruate. Menstrual blood is the result of the deterioration of the lining of the uterus, if conception has not taken place. The flow of blood that passes out of the woman's body through the vagina is called menstruation or 'a period'. The first period of a girl is called the menarche.

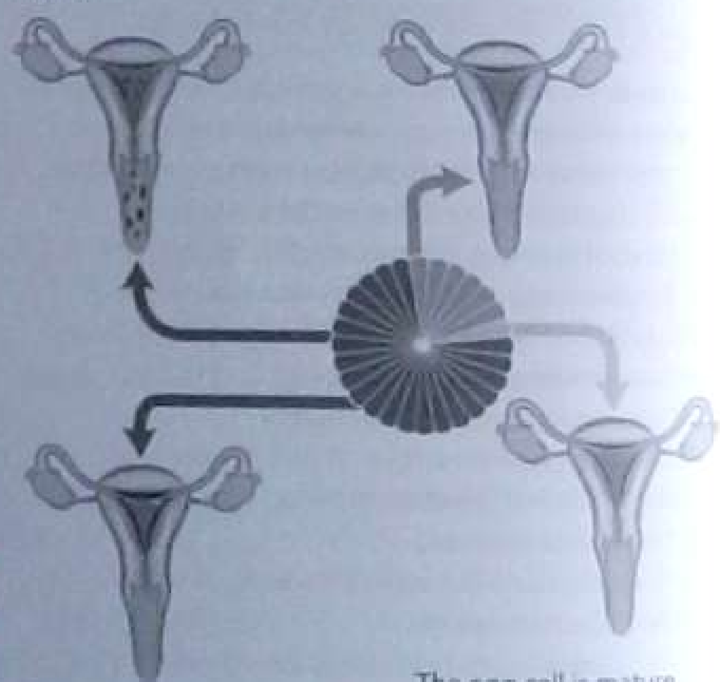


Figure 8.5 Changes to the endometrium during the menstrual cycle

Days 1–5: The menstrual cycle begins on the first day of bleeding (or menstruation). The thickened spongy layer of the endometrium (uterus lining) breaks down and passes through the vagina. During menstruation, another ovum starts to mature in one of the ovaries.

Days 6–14: The maturing ovum releases the hormone oestrogen that stimulates the endometrium in the uterus to form a new layer of spongy tissue. On Day 14, the mature ovum is released from the ovary into the Fallopian tube. This is called ovulation.

Days 15–28: A yellowish body called the corpus luteum develops in the ovary where the ovum has been released. The corpus luteum produces the hormone progesterone that stimulates the tissue of the endometrium to thicken to prepare for the possible implantation of a fertilised ovum. The ovum passes down the Fallopian tube to the uterus. If there are sperm present, fertilisation can occur.

If the ovum is not fertilised, it passes through the uterus to the vagina and out of the body. The corpus luteum degenerates and stops producing progesterone. With no progesterone present, the endometrium breaks down again, restarting the menstrual cycle.

Exercise 8.3

1. Name one hormone that is produced in the ovary.
2. Where in the body does fertilisation (conception) normally take place?
3. What is the function of the lining of the uterus after an ovum has been fertilised?
4. The graphs in Figure 8.6 (middle section) show the levels of the hormones, oestrogen and progesterone at different times during the menstrual cycle. It also indicates the thickness of the endometrium and temperature levels throughout the cycle. Based on what you have learnt and on the information in this graph, answer the questions that follow.

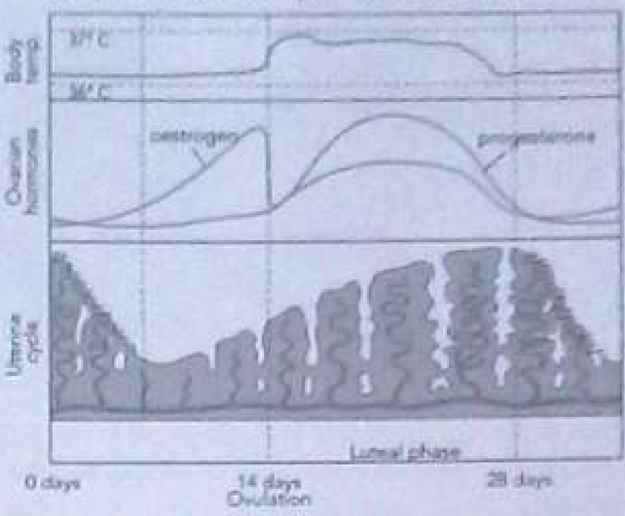


Figure 8.6 Hormone concentrations during the menstrual cycle

a) When during the menstrual cycle does ovulation occur?
b) Name the hormone produced by the corpus luteum on Day 14 and give its function.
c) Explain why the oestrogen level drops on Day 14.
d) What is the function of oestrogen?
e) Explain the relationship between oestrogen and the uterus lining.
f) How would a woman know she was ovulating if she took her temperature each day?
g) Provide evidence from the graph to indicate that fertilisation did not take place.

Role of the placenta

The **placenta** begins to form during the third week of pregnancy as tiny finger-like projections called villi (singular: villus) develop from the embryo. The placenta is shaped like a disc and acts as a filter between the mother's blood and the baby's blood, so that their blood never mixes.

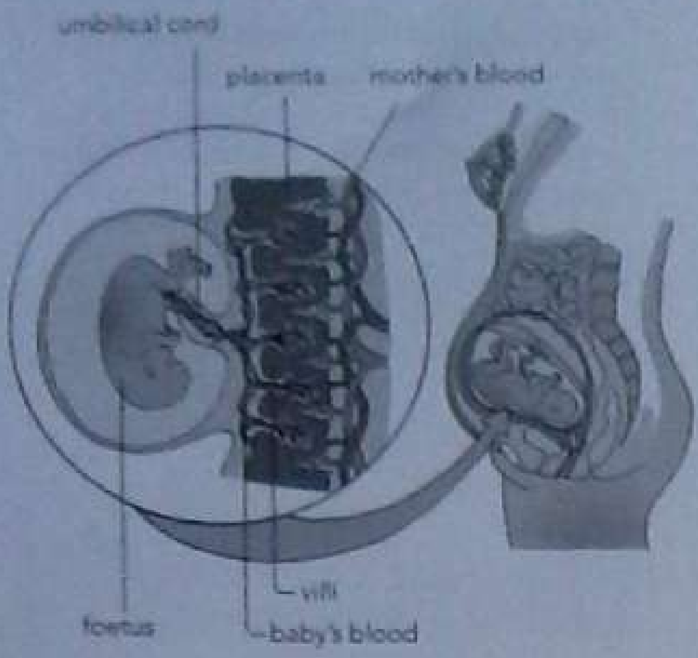


Figure 8.7 Foetus developing in the uterus and the placenta

Substances such as nutrients, oxygen and waste products move between the blood of the developing baby and the mother through the placenta. Antibodies also pass from the mother to the baby in this way. Most bacteria, viruses and some substances that may harm the developing baby are prevented from entering the foetal circulation.

The placenta also produces the hormone progesterone to maintain the endometrium during pregnancy. The developing baby is attached to the placenta by the umbilical cord during the gestation period, that is, the period from fertilisation to birth. Gestation, in humans, is 40 weeks.

Exercise 8.4

1. List the substances that are exchanged between mother and baby through the placenta.
2. How does the placenta form?
3. Define the term 'gestation' and state how long it is in humans.

Summary

- The reproductive system is the system that ensures the continuation of the species by producing offspring.
- The main organs in the male reproductive system of humans include the two testes, the sperm duct, the scrotum and the penis.
- In humans, the male reproductive organs are specialised to produce sperm and deliver them to the female.
- The main organs in the female reproductive system of humans include the two ovaries, the two Fallopian tubes, the uterus and the vagina.
- In humans, the female reproductive organs are designed to produce ova and to hold and protect the growing embryo during pregnancy.
- The ovaries produce hormones that control the menstrual cycle.
- The menstrual cycle is the process that prepares a woman's body for pregnancy.
- The hormones oestrogen and progesterone control the menstrual cycle.
- The placenta is shaped like a disc and it starts to develop during the third week of pregnancy.
- The placenta acts like a filter between the mother's blood and the baby's blood.
- Substances such as nutrients, oxygen, antibodies and waste products move between the blood of the developing baby and the mother through the placenta.
- The developing baby is attached to the placenta by the umbilical cord.
- The placenta produces the hormone progesterone to maintain the endometrium during pregnancy.
- Gestation in humans is regarded as 40 weeks.

Glossary

acrosome – the structure in the sperm cell containing enzymes to break down the membrane of an ovum

cervix – ring of muscle at the base of the uterus leading to the vagina

ejaculation – the release of semen from an erect penis

embryo – in this context, a developing human offspring in the first eight weeks after conception

endometrium – inner lining of the uterus

foetus – a human offspring in the uterus in the later stages of development

gestation – period from conception to birth

heritable – characteristics that can be transmitted from parent to offspring

mitochondria – the organelles in the sperm cell providing it with energy (singular: mitochondrion)

ova – the female sex cells (singular: ovum)

ovary – organ producing female egg cells or ova

ovum – a female egg or sex cell (plural: ova)

placenta – a disc of tissue forming in the wall of the uterus through which substances are passed between mother and child during gestation

scrotum – sack enclosing and protecting the testes

semen – the reproductive fluid containing the sperm

sperm – the male sex cell

testes – male organs enclosed in scrotum producing sperm (singular: testis)

urethra – tube leading from the bladder though the penis and opening at its tip

uterus – organ where the embryo develops during pregnancy

vagina – the canal between the uterus and the outside genitals of the female

Revision questions

1. A disc of tissue that forms in the wall of a uterus.
   A nucleus B placenta
   C embryo D foetus (2)
2. The sack of skin protecting the testes.
   A ejaculation B duct
   C semen D scrotum (2)
3. What is the advantage of having the testes held outside the body in the scrotum? (2)
4. What is the name of the mixture of sperm and fluid travelling through the urethra? (1)
5. Describe how the foetus obtains food and gets rid of waste products. (4)
6. Where does fertilisation take place in a human female? (1)
7. Give another name for the:
   a) female sex cell (1)
   b) male sex cell (1)
8. Match each of the following terms with the correct description

Term	Description
ovum	a) ring of muscle separating the uterus and vagina
ovary	b) glands producing sperm cells
ovulation	c) male sex cell
Fallopian tube	d) release of an ovum once a month
uterus	e) area where the embryo implants and grows
cervix	f) female sex cell
vagina	g) nourishes and activates sperm cells
sperm	h) passage for menstrual flow and for the baby during birth
testes	i) the duct for the ovum to pass through
umbilical cord	j) joins the baby and the placenta
	k) female sex organ that produces ova

(10)

9. What is the name of the process in which the male and female sex cells fuse? (1)

TOTAL: 25

Unit 9 Health and disease

Objectives

- List sexually transmitted infections (STIs).
- Describe the signs and symptoms of STIs, such as, gonorrhoea, syphilis, chancroids and genital herpes.
- State the causative agents of gonorrhoea, syphilis, chancroids and genital herpes.
- State the control methods and treatment of gonorrhoea, syphilis, chancroids and genital herpes.
- Describe the signs and symptoms of the diseases known as malaria, Ebola virus disease (EVD), typhoid and cholera.
- State the causes of malaria, Ebola virus disease, typhoid and cholera.
- Explain how malaria, Ebola virus disease, typhoid and cholera are treated.
- Describe the effects of tobacco smoking on people's health.
- Describe how the excessive consumption of alcohol affects people's health.
- Explain how the use of Mandrax and cannabis affects people's health.
- Outline what the effects of breathing solvents are on people's health.

Introduction

Infectious diseases are caused by **pathogenic** microorganisms such as bacteria, viruses, protozoa, worms and fungi. They can be passed on from an infected person to a non-infected person (for example, through bodily fluids or skin-to-skin contact) or spread through some other means (contaminated food or water and animal bites). Infectious diseases, or **communicable** diseases, have different **signs** and **symptoms** and these are the focus of the first part of this unit. Later on in the unit, you will learn about how certain habits, such as smoking, excessive alcohol consumption and the use of drugs affect people's health.

Sexually transmitted infections (STIs)

Sexually transmitted infections (STIs) are also referred to as sexually transmitted diseases (STDs) or venereal diseases. They are contracted by direct sexual contact with an infected person. The most common sexually transmitted diseases are gonorrhoea, syphilis, chancroids, HIV/AIDS and genital herpes.

Gonorrhoea

Gonorrhoea is caused by the bacterium *Neisseria gonorrhoeae* (also known as *Gonococci*, or *Gonococcus*) through direct sexual contact. Both males and females can be infected. Infections usually occur in the urethra, cervix, anal canal and the conjunctiva (mucous membrane of the eye). The rate of gonorrhoea **acquisition** for males is 35% after a single exposure and this figure rises to 75% after multiple sexual contacts with the same infected person. Gonorrhoea can also lead to sterility through infecting the prostate gland in males and the Fallopian tubes in females.

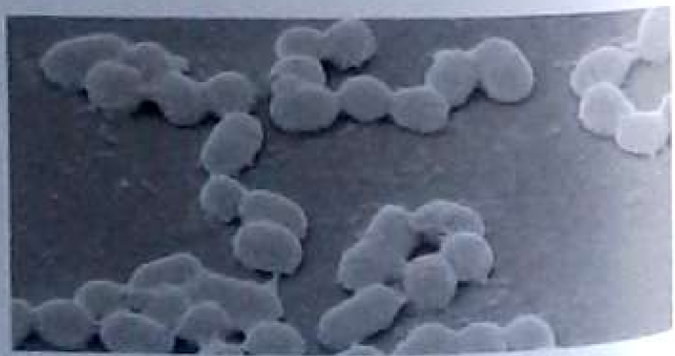


Figure 9.1 *Neisseria gonorrhoeae*

Signs and symptoms of gonorrhoea

Gonorrhoea causes a characteristically painful, smelly urethral discharge in men. The discharge can be green, yellow or white. Men suffer from a burning sensation during urination. In women, it commonly infects the cervix. Women may suffer from swelling of the vulva, an abnormal vaginal discharge and abnormal menstrual bleeding. In both sexes, untreated gonorrhoea may spread to other parts of the body, including the heart valves, **meninges** surrounding the brain and the joints. When it reaches the joints, it causes severe arthritis.

Treatment of gonorrhoea

Gonorrhoea is treatable with antibiotics, such as penicillin and tetracycline, although some strains of the bacteria have become resistant to treatment. A previously cured infection does not confer immunity. In other words, gonorrhoea can be contracted again.

Syphilis

This is a bacterial infection caused by *Treponema pallidum*. It is passed on during sexual intercourse and from mother to baby during childbirth. The bacteria enter the body through cuts in the **epithelium** and by penetrating into mucous membranes. In a pregnant woman, the bacteria cross through the placenta to infect the foetus. Babies with **congenital** syphilis are usually very weak and ill, living only a few hours after birth.

Signs and symptoms of syphilis

The disease develops in three stages. During the first stage, a lump appears on the penis, vagina or cervix. This turns into an ulcer that disappears after about six weeks. This stage may pass unnoticed.

In the second stage, starting six to eight weeks later, the infected person develops a mild fever and a rash or sores around the **genitals**, anus, mouth and eyes. The lymph glands, especially in the neck, may also swell.

The third stage can occur as many as ten or more years after infection. The bacteria will have invaded most parts of the body and they will affect many tissues and organs. This is the most destructive stage, as the bacteria destroy nerves, cause heart disease, blindness, sometimes insanity and, eventually, death.

Figure 9.2 An example of a patient suffering from third stage syphilis

Treatment of Syphilis

Syphilis can be treated with penicillin and other antibiotics, but only during the early stages. Once the disease has reached the third stage, it is difficult to cure as the **lesions** may have already caused permanent damage to organs.

Chancroid (venereal ulcers)

The **causative agent** of this sexually transmitted infection is the bacterium *Haemophilus ducreyi*. The bacteria attack the tissue around the external areas of the reproductive organs of both men and women. An open sore, referred to as a chancroid or venereal ulcer, appears on the outside of the **genitals**. The ulcer can bleed or produce a **contagious** fluid that can spread bacteria during sexual intercourse. Chancroid can be acquired through touching an open sore as well as through sexual intercourse.

Signs and symptoms of chancroids

Small bumps appear on the penis or the **labia** three to five days after sexual intercourse or infection. In men, this develops into open sores on the penis and scrotum. In females, the bumps turn into ulcers that cause a painful burning sensation during urination or bowel movements. The sores usually heal quickly, but they may persist for months if left untreated.

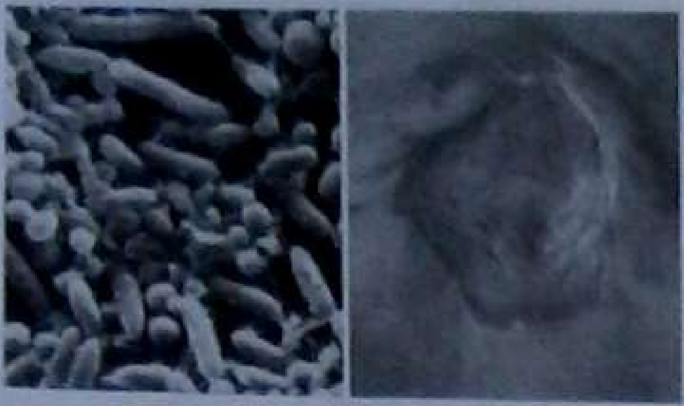


Figure 9.3 a) and b) Chancroid bacteria and an example of a chancroid ulcer

Treatment of chancroid

Chancroid is treated with antibiotics, such as tetracycline and sulphanilamide. Antibiotics decrease scarring after the healing of the venereal ulcers.

Genital herpes

The herpes simplex virus is categorised into two groups, the herpes simplex virus type 1 (HSV-1) and the herpes simplex virus type 2 (HSV-2). You can get the herpes simplex virus by having sexual intercourse with an infected person. Fluids found in herpes sores also carry the virus and can cause infection. The h. simplex virus enters through the skin and the infection afterwards spreads to nerves in the skin.

Signs and symptoms of genital herpes

Most people who are infected by the h. simplex virus do not have symptoms or signs. When signs occur, they are small blisters that eventually break open and become raw, painful sores. This causes itching in the infected area. The sores later form scabs and heal within a few weeks. Flu-like symptoms with fever and swollen lymph nodes may also appear.

Treatment of genital herpes

There is no cure for genital herpes, but the symptoms can be prevented with treatment. Antiviral medication reduces the pain and discomfort from outbreaks of sores. Taking daily medication can also suppress the virus and reduce the risk of infecting others.

The effects of sexually transmitted infections

Sexually transmitted infections (STIs) are a huge health and economic burden for developing countries. Herpes and syphilis dramatically increase the chances of getting infected with HIV. According to the U.S. Centers for Disease Control and Prevention, people with STIs are at least two to five times more at risk of getting HIV through sexual intercourse. Syphilis in pregnant women is linked with a low birth weight of babies, premature birth and stillbirth. Gonorrhoea causes pelvic floor infections and infertility in women.

Controlling sexually transmitted infections

In Zimbabwe, the Ministry of Health is running health awareness campaigns to educate and inform the public on the effects of sexually transmitted diseases. Programmes promoting condoms, **vaccines** and screening can help reduce the incidence of STIs. The mass treatment of vulnerable groups (such as pregnant women) and high-risk groups (such as sex workers) helps to reduce numbers of new infections.

The best way to prevent STIs is abstinence, in other words, not to have sex. If a person is sexually active, it is important to practice safe sex, by always using a barrier, such as latex condoms, during sexual intercourse. This is not a guarantee against STIs, but condoms can significantly reduce the risk of STIs and HIV. Limiting the number of sexual partners reduces a person's risk to get STIs. A sexually active person should get regular tests for STIs. The guidelines are twice a year for gonorrhoea and once a year for syphilis. Sexually active women should have an annual **Pap smear** to detect cervical cancer.

Exercise 9.1

1. List the sexually transmitted infections about which you have learnt.
2. State the causative agents of these STIs and describe how they are spread.
3. What kinds of behaviour put sexually active people at a higher risk to acquire STIs?
4. What kinds of behaviour can reduce a person's risk of contracting STIs?
5. What is the only behaviour that can eliminate the risk of contracting STIs?
6. a) Explain why you think many people find it difficult to talk about STIs with a:
   i) partner
   ii) parent
   iii) doctor.
   b) What are possible consequences of avoiding these talks?
7. Many people believe that if someone looks 'clean', they cannot have an STI, while a person may have no symptoms and may thus infect people unknowingly.
   a) What is the only way to know for sure that someone does not have an STI?
   b) Where can a person go for information and testing?

Other communicable diseases

You will remember that a communicable disease is a disease that can be passed on from person to person or in some other way. Infections are caused by **pathogens**, such as viruses, bacteria or protozoa entering the body and causing illness.

Here are some examples of pathogens commonly found in Zimbabwe and the diseases they cause:

Pathogen types	Infectious disease
Bacteria	cholera, typhoid fever, tuberculosis (TB)
Protists	malaria, sleeping sickness
Viruses	Ebola virus disease, HIV/AIDS, polio, influenza, chicken pox

Healthy habits

Healthy habits, such as washing your hands, cleaning and disinfecting surfaces, covering your mouth and nose when you sneeze, not sharing personal items and staying at home when you are ill are all ways of preventing the spread of disease.

Malaria

Malaria is caused by a **plasmodium**, a parasitic **protozoan**, found in the salivary glands of the female mosquito of the *Anopheles* genus. The *Anopheles* mosquito is a **vector**, that is, an insect carrying a **parasite** to its next host. The malaria parasite completes its life cycle partly in the female mosquito and partly in humans.

The life cycle of the malarial parasite.

When the *Anopheles* female mosquito (first vector) bites a human, the malaria parasites are injected into the bloodstream. The malaria parasites travel in the blood to the liver and invade the liver cells. The malaria parasite reproduces **asexually** in the liver cells, forming thousands of parasites.

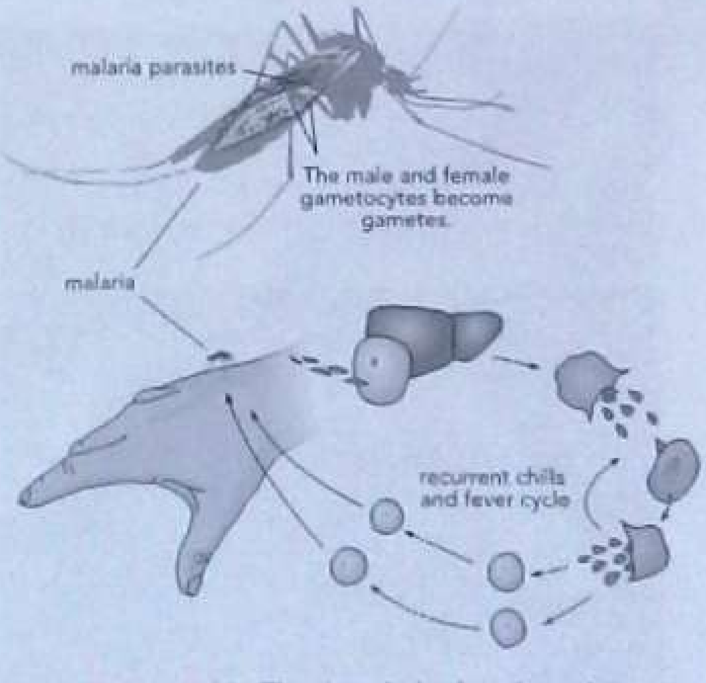


Figure 9.4 a) and b) The *Anopheles* female and the malaria cycle

The parasites are released from the liver into the blood, where they enter the red blood cells. In the red blood cells parasites reproduce asexually. The parasites burst the red blood cells causing cycles of violent feverish attacks of malaria. The released parasites then infect new red blood cells.

Some of the parasites become male and female gametocytes. When a mosquito (second vector) bites an infected human, it sucks up the blood and the gametocytes pass into the mosquito's intestine. Inside the mosquito, the male and female gametocytes become gametes. Fertilisation (the fusion of a male and female gametocyte) takes place in the mosquito's intestine and the parasites mature here. Mature parasites finally leave the mosquito's intestine and migrate to its salivary glands.

Signs and symptoms of malaria

The symptoms of malaria appear about two weeks after infection. These symptoms include high fever, shivers and sweats, headaches, vomiting and an enlarged spleen. In some cases, the malaria parasite attacks the brain and the patient can fall into a coma and die.

Controlling and treating malaria

There is no vaccine for malaria, but the disease can be prevented by taking preventative drugs such as quinine and chloroquine when visiting a malaria area. Other preventative drugs are paludrine, deltraprim, malasone and malaquine. High rates of malaria occur in the lowveld of Zimbabwe, in the Zambezi escarpment and in Mashonaland Central.

Figure 9.5 Sleeping under nets will reduce the chance of getting malaria

Other ways of preventing the disease are to sleep under mosquito nets, to spray insect repellent chemicals on the skin and to wear long-sleeved clothes from early evening when mosquitoes become active. The best protection against malaria is to avoid being bitten. And, because children cannot be given antimalarial drugs, it is thus very important to take special care that they are not bitten.

Drain any stagnant water to destroy breeding areas. Spray oil on the surface of stagnant water such as drains to suffocate and kill mosquito larvae. Do not leave stagnant water in buckets or leave old tyres and litter lying where they can catch up water and become breeding places for mosquitoes. In some rural areas, the poison DDT is used to spray houses to kill mosquitoes. Malaria mosquitoes can also be controlled biologically through the toxins produced by the group of bacteria referred to as *Bacillus thuringiensis* and by stocking ponds with fish that feed on mosquito larvae. Cut down tall grasses to destroy their habitat, breeding places and food.

Typhoid

Typhoid is caused by the bacterium *Salmonella typhosus*. It is common in most parts of the world, but Southern Asia, Africa, Latin America, India and Pakistan are high-risk areas. The bacteria spread through contaminated food and water. The bacteria enter the small intestine and the bloodstream of a person that has come into contact with contaminated food or water. In the blood, the bacteria are carried by the white blood cells to the liver, spleen, gall bladder and bone marrow where they multiply very quickly.

Signs and symptoms of typhoid

Symptoms of typhoid include high fevers, weakness, stomach pains, headaches, a poor appetite and a rash (rose spots) on the abdomen and chest. The first signs of infection are a high temperature, stomach pains and diarrhoea. Typhoid can be diagnosed by testing a stool sample or blood samples.

Figure 9.6 *Salmonella typhosus* causes typhoid.

Controlling and treating typhoid

Treatment with antibiotics usually leads to patients recovering fully within seven to ten days. There are vaccines for people travelling to high-risk areas. Other methods of control are putting good sanitation in place, giving people access to clean water, ensuring waste disposal and protecting food supplies from contamination. Personal hygiene is critical to avoid contracting typhoid. People with typhoid should also not handle or prepare food.

Ebola virus disease (EVD)

EVD is caused by the deadly *Ebola virus* that is transmitted to humans through close contact with the blood, secretions and organs of animals such as chimpanzees, gorillas or fruit bats that are infected. This contact happens mostly when people hunt bush meat in the rain forests. Human-to-human transmission of the Ebola virus takes place when a person touches the broken skin of an infected person or comes into contact with infected body fluids such as blood, saliva, sweat, vomit, semen and breast-milk. Touching a person who has died from EVD or even touching contaminated bedding or clothing may lead to infection. A person is infectious as long as one's blood contains the virus.

Figure 9.7 The Ebola virus under a microscope

Signs and symptoms of EVD

The **incubation period** for EVD is 2 to 21 days after infection. The first symptoms of Ebola virus disease are headaches, high fever, weakness, muscle pain and a sore throat. The virus destroys all tissues and organs of the body, except for the skeletal muscles and bones. The patient will suffer from a high temperature, vomiting, diarrhoea and a rash about ten days after the appearance of the first symptoms. The rash is caused by blood clots that weaken blood flow and the spots get bigger as the disease progresses. By day 11, there will be bruising, brain damage and external bleeding from the eyes, nose, mouth and anus. By day 12 to 16, there is massive internal bleeding of the lungs, brain, liver, intestines, kidneys, testicles, and breast tissue. The person loses consciousness, will have seizures and will eventually die.

Controlling and treating EVD

Figure 9.8 Volunteers with their protective gear helping to bury EVD victims in the Democratic Republic of the Congo

There is no cure for EVD so that treatment is limited to supportive therapy. Very ill patients require intensive supportive care: balancing the patient's fluids and electrolytes, maintaining their oxygen levels and blood pressure and treating complicating infections early. The Ebola virus kills about 65% of its victims. To protect yourself from getting EVD, make sure you wash your hands with soap and water or with an alcohol-based disinfectant. People should cover their nose and mouth when coughing and sneezing, using a handkerchief or tissue. Avoid contact with blood and bodily fluids. Do not handle clothes, bedding, needles, and medical equipment that may have been contaminated with an infected person's blood or body fluids. Do not touch someone at a funeral who has died from EVD.

Cholera

Cholera is a bacterial disease caused by some strains of *Vibrio cholerae*. It is mostly **waterborne** and is common in areas with poor sanitation and poor water purification facilities. This is why the Zimbabwean government strives to protect water sources. The disease also spreads through food that is contaminated by human or animal faeces, by human carriers, flies and rodents.

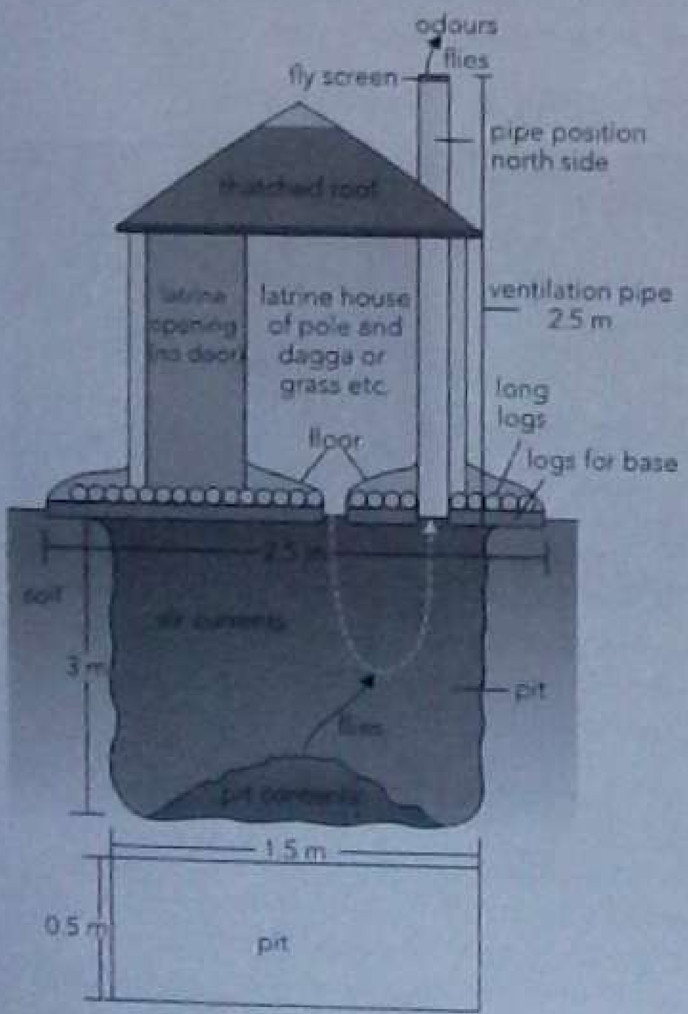
Signs and symptoms of cholera

A cholera patient will suffer from watery diarrhoea (rice water) and vomiting. This can lead to dehydration and, if fluids and electrolytes are not replaced, the person will go into a coma and will die.

Controlling and treating cholera

Cholera can be treated by administering tetracycline and chloramphenicol to the patient. There are vaccinations against cholera. To prevent the spread of cholera, good food hygiene is essential. Always use proper toilet facilities so that the faeces do not end up in water sources. In Zimbabwe, people in the rural areas are asked to build Blair pit toilets.

Wash your hands with soap and water after using the toilet. It is important to have enough treated or boiled clean water for drinking and cooking. Do not let children play in dirty pools, rivulets or stormwater outlets. Do not let water sources become contaminated by allowing sewage to be washed into rivers by rain.



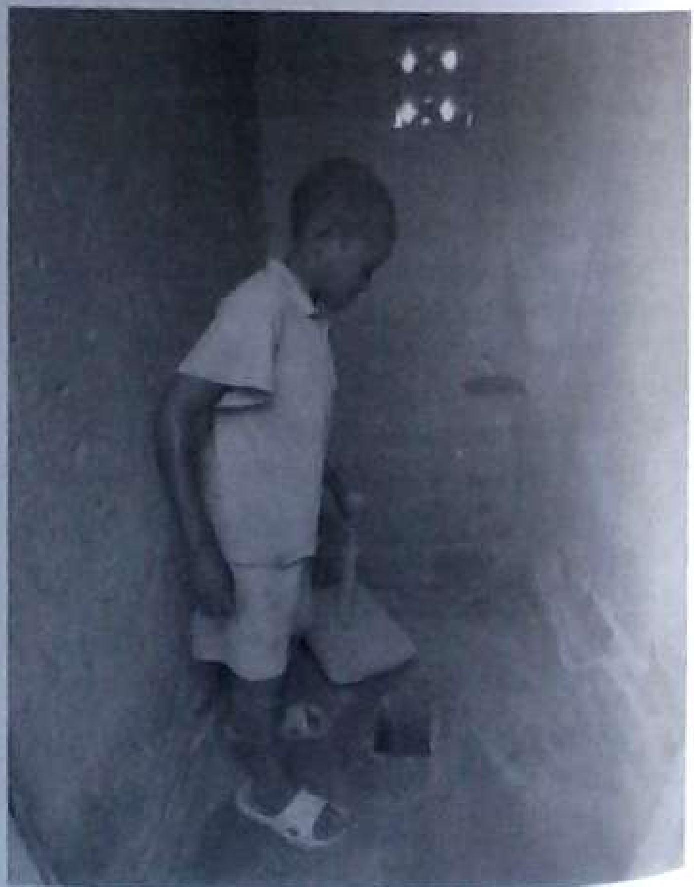


Figure 9.9 a) and b) A diagram of the Blair pit toilet and a picture of it from inside

Exercise 9.2

1. The table below provides a summary of various diseases. Study it carefully and answer the questions that follow.

Type of disease	Name	Incubation period	Signs and symptoms
Bacterial	syphilis	3 to 9 weeks	ulcers on genital organs, flu-like symptoms, skin rash
	typhoid	7 to 14 days	weakness, sore throat, coughing, abdominal pain, diarrhoea, fever
Viral	Ebola virus disease	14 to 16 days	flu-like symptoms, nausea, vomiting, chest pains, massive haemorrhaging
	measles	8 to 14 days	high fever, painful eyes, harsh cough, flat red spots starting at the neck and spreading to the rest of the body
	mumps	14 to 21 days	mild fever, swelling of the glands in front of and around the ears, headaches
	influenza (flu)	2 to 3 days	high fever, sore throat, chills, headaches, pain, congestion, coughing

a) How many types of diseases are described?
b) How many diseases are described?
c) What are the symptoms of typhoid?
d) Which diseases are associated with a cough?
e) Which diseases are NOT associated with fever?
f) Which diseases would a doctor treat with antibiotics?
g) How can people prevent getting typhoid?

2. Answer the following questions about malaria:
a) Explain why the plasmodium causing malaria is a parasite.
b) Explain the importance of the female mosquito in the life cycle of the parasite that causes malaria.
c) Suggest three control methods that the local council can do to help combat the disease or reduce the number of infections in rural areas where malaria occurs.

Lifestyle diseases and substance abuse

Lifestyle diseases are caused by a person's habits or the way people live their lives. Common examples are alcohol and substance (drug) abuse, smoking, a lack of physical activity and unhealthy eating. In this part of the unit, you will learn about the effects of smoking, excessive drinking of alcohol and the use of specific drugs.

The effects of tobacco smoking on your health

Tobacco smoke affects people's respiratory systems in many ways as it contains over 4 000 harmful and poisonous substances. Among these, tar and carbon monoxide are known **carcinogens**, that is, substances causing cancerous tumours by making cells grow and divide uncontrollably. Cigarette smoke is thus associated with lung cancer.

Tar is also absorbed by the lungs and the lining inside the bronchi and bronchioles. It sticks to the hairs whose movement is supposed to keep dust, pollution, unwanted particles and microorganisms from getting into your lungs. Excess mucus, together with tar, dust and microorganisms, thus collects in the lungs. Bacteria breed in the mucus, causing bronchitis and lung infections.

Emphysema is yet another disease caused by cigarette smoke. Tar irritates the alveoli walls and they finally burst, leaving large spaces or blebs. The blebs fill up with mucus and reduce the surface area for gaseous exchange. Emphysema causes shortness of breath as you cannot absorb enough oxygen. Carbon dioxide also collects in the blebs, eventually leading to suffocation.

Cigarette smoke is also associated with heart disease. Carbon monoxide is absorbed from the lungs into the bloodstream where it combines with haemoglobin in the red blood cells. With carbon monoxide attached to the haemoglobin, less oxygen is carried to the cells for respiration. The body increases its breathing and heart rates because of the shortage of oxygen. The heart works harder and chances of getting a heart attack increase. Coughing is a short-term effect of tobacco smoking, while it also acts as a depressant of the nervous system. Nicotine, a substance found in tobacco, is addictive so that it is difficult to stop the smoking habit.

Newborn babies whose mothers smoked while pregnant usually have lower birth weights and often have breathing problems. Children who are exposed to their parents' smoke are also more prone to diseases than other children.

Excessive alcohol consumption

Chemical substances such as alcohol can enter your brain. They change the way that you think and feel. Alcohol has many effects on your nerve functions. When under the influence of alcohol, pain messages are impaired and it difficult to coordinate body movements. It can make the user feel happy and carefree and they will lack judgement when in dangerous situations such as driving. Drunk drivers cause accidents that kill many people every year. The long-term use of alcohol causes liver cirrhosis or liver damage. The liver is severely scarred so that it shrinks and hardens. The hardened tissue reduces blood flow through the liver, leading to poor liver function. This, in turn, affects many body functions. Alcohol is a depressant and irresponsible drinking can lead to addiction, depression, memory loss, aggression and anxiety.

Alcohol abuse makes people lose their inhibitions so that they behave impulsively. It can even lead to actions such as self-harm and suicide. Alcoholism is also linked to mental conditions such as having hallucinations and believing that you are being persecuted.

Heavy drinking can affect relationships with family and friends when it leads to accidents at home or violence. A person's drinking problems can influence the mental health of family members, causing them to experience anxiety, fear or depression. Spending money on alcohol and the loss of wages can often leave family members destitute.

Drinking heavily has an impact on the work environment. There is ample evidence that people with alcohol dependence and drinking problems are on sick leave more frequently than other employees, with a significant cost to employers and social security systems. Workplace accidents that may be fatal can be linked to alcohol abuse. Heavy drinking at work may reduce productivity. Performance at work may be affected both by the volume and pattern of drinking. Co-workers often notice heavy drinkers' lower performance, their personal relationship problems and their lack of direction, although drinkers themselves are often unaware of their problems. Alcohol abuse may lead to unemployment that may, in turn,lead to an increase in drinking due to hopelessness.

A developing foetus is affected by what the mother does during the pregnancy. The first four months of pregnancy is the most important period for brain development. Everything the mother eats or drinks goes into the unborn baby's blood as well. Alcohol usage during pregnancy can make the baby addicted to alcohol. Some babies are born brain-damaged and they will have learning disabilities, because their mothers drank alcohol regularly during the pregnancy. This condition is called Foetal Alcohol Syndrome (FAS).

Physical characteristics (both visible and blurred on the photo)

- small head circumference
- skin folds at the eye corners
- small eye slits
- small midface
- short nose
- low nasal bridge
- indistinct philtrum
- thin upper lip

Figure 9.10 Typical facial features of a child with FAS

The effects of solvents, Mandrax and cannabis on the user's health

Drugs can seriously affect the central nervous system and damage your health. These include solvents such as fast-drying glues, cannabis (marijuana or dagga) and Mandrax. Sniffing glue can cause damage to organs and affect your memory and intelligence. Both Mandrax and cannabis contain **hallucinogens** and have **sedative** properties. When these drugs enter the brain, they change the way you think and feel. They change the way impulses travel to the brain and how the brain interprets them. These drugs make a person feel happy and create weird dreams. The nerves in the brain that have to do with memory and learning are damaged. Brain damage can be permanent. Other effects of these drugs are anxiety, confusion, disorganised thinking and slurred speech. Taking drugs not only damages the brain, but it can also affect other body parts, such as the heart muscles. Drugs are addictive and lead to a loss of self control. When people become addicted to these drugs, it can destroy them and their family. Pregnant woman who are drug abusers often give birth to babies that are also addicted to the drug. Users often have red, puffy eyes, especially if Mandrax is taken together with cannabis.

The influence of substance abuse on families

When someone is addicted to drugs or alcohol, it affects the whole family. The drug addict or alcoholic becomes unpredictable and family members do not know what to expect. Family members may have fights, because of the problems the drug addict or alcoholic is causing. Some family members may try to support the addict or alcoholic while others resent the addict or alcoholic. Sometimes family members feel ashamed, because the addict or alcoholic behaves badly in front of friends and neighbours. Addicts or alcoholics need money to feed their addiction and they may steal money or sell things belonging to the family in order to pay for drugs. Treatment and rehabilitation centre or hospital costs may place a heavy burden on families. This may lead to financial insecurity and poverty when money runs out. Some addicts or alcoholics become violent when they are under the influence. Family members then suffer physically and emotionally.

Exercise 9.3

1. Explain the term 'lifestyle disease'.
2. Name substances that are related to lifestyle diseases.
3. How does smoking tobacco affect the smoker's health?
4. What are the negative effects of alcohol on the body?
5. What is Foetal Alcohol Syndrome (FAS)?
6. Describe how you can recognise a child with FAS.
7. What is a drug addict?
8. Give examples of drugs abused by teenagers.
9. Discuss why you think teenagers abuse drugs.
10. Explain why drugs are dangerous.

Summary

- Disease is a disorder or malfunctioning of the body.
- Each disease presents a certain set of signs and symptoms.
- Infectious diseases are caused by pathogens such as viruses, bacteria, protozoa, insects and worms.
- Sexually transmitted infections or diseases are acquired by direct sexual contact with an infected person. This generally occurs during sexual intercourse.
- The most common sexually transmitted infections or STIs are gonorrhoea, syphilis, chancroids, HIV/AIDS and genital herpes.

- Cholera is caused by the bacterium *Vibrio cholerae* that is transmitted through water or food contaminated with faeces or through contact with an infected person.
- Malaria is caused by a plasmodium. The disease is transmitted by female *Anopheles* mosquitoes that transfer from infected to uninfected people.
- Typhoid is a disease caused by the bacterium Salmonella typhosus. Typhoid is common in most parts of the world, but high-risk areas are Southern Asia, Africa, Latin America, India and Pakistan. The bacteria are spread by contaminated food and water.
- Ebola virus disease is caused by a deadly virus that is transmitted to humans through close contact with the blood, secretions and organs of infected animals such as chimpanzees, gorillas or fruit bats. Human-to-human transmission is also possible.
- In the context of drug abuse, drugs are chemical substances that alter physical or mental functions.
- Substance abuse is the taking of a substance in such a way that it may harm the user.
- Alcohol abuse is implicated in a range of social problems such as family breakdown, petty crime and driving under the influence of alcohol.

Glossary

acquisition – contraction of a disease, because of an environmental factor and not because it is inherited or present at birth
asexually – related to reproduction where only one parent is involved
carcinogen – something that causes cancer
causative agent – in the context of disease, it is what causes the disease
communicable – transmissible, that can be passed on or infectious
congenital – present at birth or existing from birth
contagious – transmitted by contact
epithelium – the tissue that forms the outer layer of the body surface and that lines many hollow structures
genitals – the external reproductive organs
hallucinogen – a drug causing you to hallucinate or see things that are not there
incubation period – the phase through which germs pass before the first symptoms and signs of the disease they cause appear
labia – the skin folds enclosing the vulva
lesion – wound or changes in tissue due to a disease
meninges – three membranes enclosing the brain and the spinal cord
Pap smear – a test for the early detection of cervical cancer
parasite – an organism that lives inside or on another organism at the expense of the other
pathogenic – to do with a pathogen
plasmodium – any parasite that is a protozoan of the genus *Plasmodium*, including those causing malaria in humans
protozoan – an organism of the subkingdom Protozoa that is microscopically small and usually has only one cell (plural: protozoa)
sedative – a drug that calms or soothes you
sign – any objective evidence of a disease
symptom – a physical or mental change in a person regarded as evidence of a disease
vaccine a preparation of dead or weakened pathogens that helps you to become immune against a disease
vector a carrier of a disease
waterborne carried by water

Revision questions

1. An organism that is dependent on other organisms for food and shelter is called a...
   - **A** pathogen
   - **B** parasite
   - **C** vector
   - **D** bacteria (2)
2. This is a deadly virus transmitted to humans through close contact with blood.
   - **A** typhoid
   - **B** cholera
   - **C** EVD
   - **D** malaria (2)
3. Match the terms in Column A with the correct definition in Column B.

Column A	Column B
gaseous exchange	a) a slimy substance to keep surfaces moist
tar	b) taking air into the lungs
inhalation	c) condition caused by excessive alcohol consumption in pregnant woman
FAS	d) the exchange of gases in living organisms
mucus	e) substance found in cigarette smoke

(5)

4. Emphysema is a disease of the lungs. People who smoke cigarettes are more likely to suffer from emphysema. The diagrams below show lung tissue from a healthy person and lung tissue from a person with emphysema. The diagrams are drawn to the same scale.

Lung tissue from a healthy person — Lung tissue from a person with emphysema

By referring to the diagrams, explain how emphysema reduces the amount of oxygen that diffuses into the blood. (2)

5. Differentiate between the following pairs of terms.
   - **a)** Signs and symptoms of a disease (2)
   - **b)** Pathogen and vector of a disease (2)
   - **c)** Transmissible diseases and non-transmissible diseases (2)
6. **a)** With reference to alcohol and Mandrax, explain what is meant by the following terms: 'drug' and 'drug abuse'. (5)
   b) Explain the dangers of alcohol abuse in young people. (3)

TOTAL: 25

End of topic revision test

1. What makes oxygen diffuse into the bloodstream from an alveolus in the lungs?
   - A. The oxygen concentration in the alveolus is higher than in the atmosphere.
   - B. The oxygen concentration in the alveolus is lower than in the blood.
   - C. The oxygen concentration in the atmosphere is higher than the carbon dioxide concentration.
   - D. The oxygen concentration in the blood is lower than in the alveolus. (2)

2. The diagram shows a leaf from a plant kept in the Sun for 48 hours.

Which colours will be obtained if the leaf is then tested for starch with iodine solution?

	Green area	White area
A.	blue-black	blue-black
B.	blue-black	brown
C.	brown	blue-black
D.	brown	brown

(2)

3. In which physical state is water when it is absorbed and when it is lost by a plant?

	Absorbed	Lost
A.	liquid	liquid
B.	liquid	vapour
C.	vapour	liquid
D.	vapour	vapour

(2)

4. Place the stages of digestion in the correct order.
   - A. ingestion, digestion, assimilation, absorption and egestion
   - B. digestion, assimilation, ingestion, absorption and egestion
   - C. egestion, assimilation, absorption, ingestion and digestion
   - D. ingestion, digestion, absorption, assimilation and egestion. (2)

5. In what order does food pass through the following organs?
   - A. mouth, stomach, oesophagus, small intestine, large intestine
   - B. mouth, stomach, small intestine, oesophagus, large intestine
   - C. mouth, oesophagus, stomach, small intestine, large intestine
   - D. none of the above. (2)

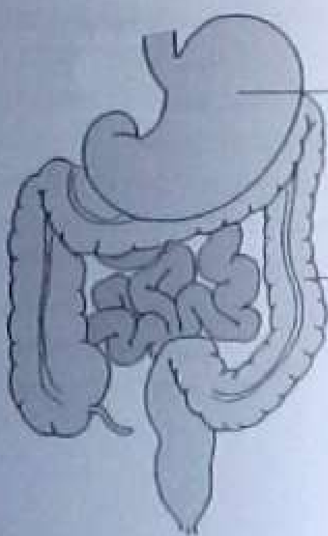
6. Sperm are made in the:
   - A. testes
   - B. sperm duct
   - C. kidneys
   - D. none of the above. (2)

7. Menstruation occurs during days ___ of the menstrual cycle
   - A. 1 to 5
   - B. 6 to 12
   - C. 13 to 15
   - D. 16 to 28. (2)

8. The loss of water from a plant is called:
   - A. evaporation
   - B. respiration
   - C. transpiration
   - D. photosynthesis. (2)

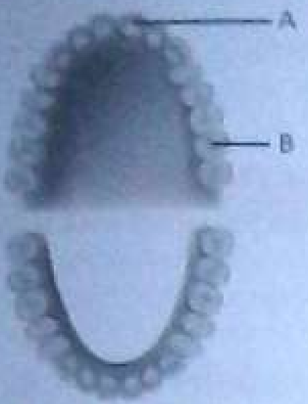
9. The rate of transpiration in plants depends on:
   - A. sunlight
   - B. air humidity
   - C. the amount of water in the soil
   - D. all of the above. (2)

10. Name the parts labelled A and B in the diagram of the digestive system shown.



   - A. A = stomach and B = large intestine
   - B. A = stomach and B = small intestine
   - C. A = oesophagus and B = small intestine (2)
   - D. A = pancreas and B = large intestine

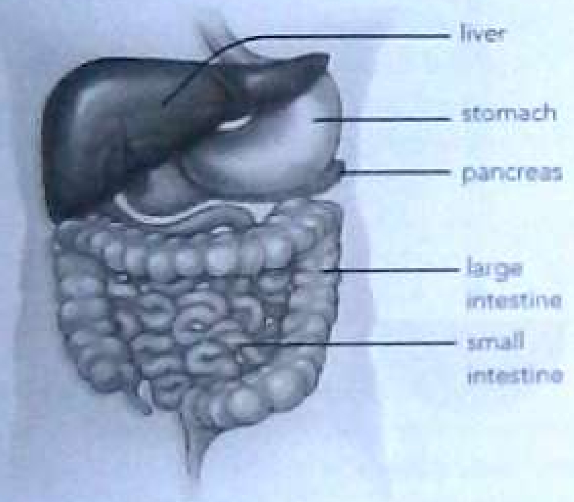
11. Study the diagram and answer the questions that follow.



a) Identify the types of tooth labelled A and B in the diagram. (2)

b) What is the main function of each type? (4)

12. The labelled diagram shows most of the organs involved in digestion and associated processes in our bodies.



Give one function for each of the five organs labelled in the diagram. The word digestion alone will not merit marks: if it is used in an answer it must be qualified in some way. (10)

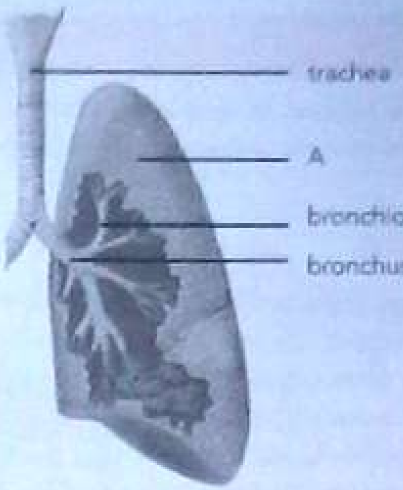
13. We would not be able to exist without enzymes. Enzymes release energy from food, help build the molecules our bodies are made of and break down waste.

a) Name a group of enzymes used in digestion. (1)

b) Name the substrate that these enzymes you have named acts upon. (3)

c) Name the product of the action of this enzyme. (2)

14. The diagram shows the structure of a human lung. Air passes in and out of the lungs, via the trachea, bronchi and bronchioles. Gaseous exchange takes place in structures labelled A.

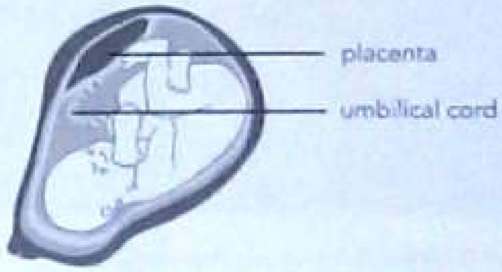


a) Name structure A. (1)

b) Draw a flow diagram showing the pathway of air into the lungs. (5)

c) How does oxygen pass into the blood in the structures labelled A. (3)

15. The diagram shows a baby in the womb. The placenta and umbilical cord are labelled.



a) Give two functions of the placenta. (2)

b) Compare the composition of substances in the umbilical vein and the umbilical artery. (4)

c) Discuss the dangers for a developing foetus if the expecting mother uses alcohol. (3)

TOTAL: 50

Unit 10 Separation

Objectives

- Describe the process of simple distillation.
- Describe the process of fractional distillation.

Introduction

In Form 1, we learnt about a variety of methods of separating mixtures. Some methods were for separating solids from other solids, some were for separating solids from liquids and others were for separating immiscible liquids (liquids that do not mix, like oil and water). In Form 3, we will look at separating liquids and solids that are in solution, using methods that will allow us to keep all components of the mixture.

Figure 10.1 Separating salt from water

Simple distillation

In Form 1, we saw how a salt water solution could be separated by evaporation. However, water was lost during the process. To avoid the loss of water we can carry out a **simple distillation** of the salt solution to separate the two.

We can also use simple distillation to separate a mixture of two liquids that have different boiling points. We use it to separate liquids whose boiling points that are not very close. For example, we could use simple distillation to separate a mixture such as ink and water. Water boils at 100 °C, but ink boils at a much higher temperature. We can therefore use the differences in their properties to distil pure water from a mixture of water and ink.

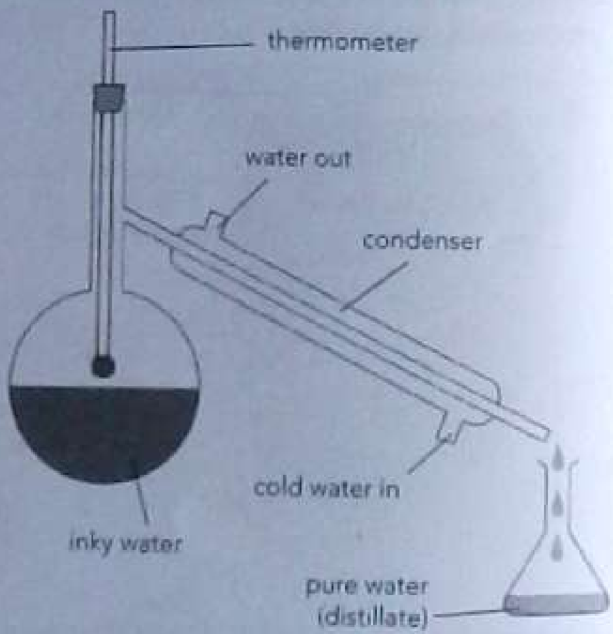


Figure 10.2 Simple distillation

When the mixture is heated, the water will boil before the ink boils, because water has a lower boiling point than ink. The water will then evaporate and pass into the condenser, where it condenses. You can then collect the pure water. The ink is left behind.

The liquid that is collected in the beaker after passing through the condenser is called the **distillate**.

Experiment 10.1

Aim: To separate salt from a salt solution using the method of simple distillation

Materials: a round-bottomed flask, a condenser, a thermometer, a beaker, a clamp stand, rubber tubing, a Bunsen burner, a salt solution

Procedure

1. Carefully set up the apparatus as shown in Figure 10.3.
2. Turn on the water tap to allow steam to be cooled in the condenser.
3. Heat the flask until all the liquid evaporates.
4. Record the temperature at which steam is collected.
5. Reduce the heat to allow crystals to form in the round-bottomed flask.

Results

The final result should be the complete separation of liquid and solid, with the salt remaining in the round-bottomed flask, and the pure liquid collected in the beaker.

Questions

1. At what temperature is steam collected?
2. What remains at the bottom of the flask when all the solution has been heated?
3. What are the advantages of distillation over evaporation

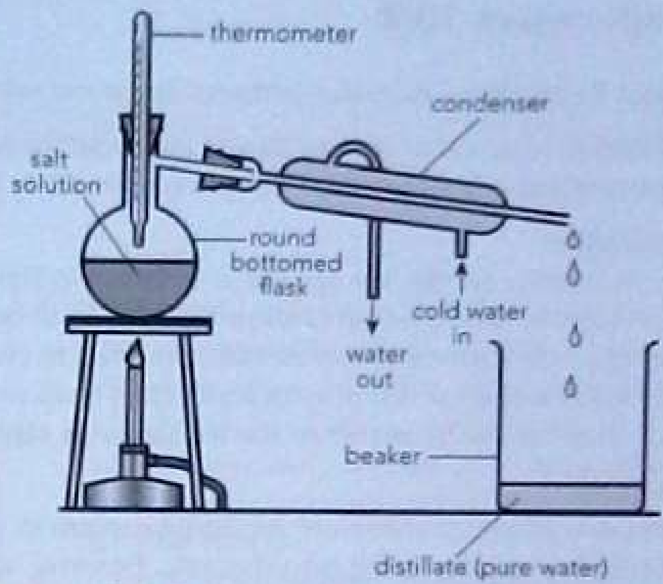


Figure 10.3 The simple distillation of a salt solution

Fractional distillation

We use **fractional distillation** to separate two liquids that are **miscible** (they mix together easily). This method is ideal when one of the liquids is more **volatile** (evaporates more easily) than the other.

Figure 10.4 shows the apparatus needed for fractional distillation. The beads in the fractionating column let the hot vapours condense and evaporate many times. This is because they offer a large surface area on which the vapours can condense, but still allow vapours to move freely through the gaps between the glass beads.

When heat is applied to the flask at the bottom, vapours of both liquids move upwards through the fractionating column. While there, they condense on the glass beads and drip back into the flask, until the temperature reached equals the boiling point of the liquid with the lower boiling point.

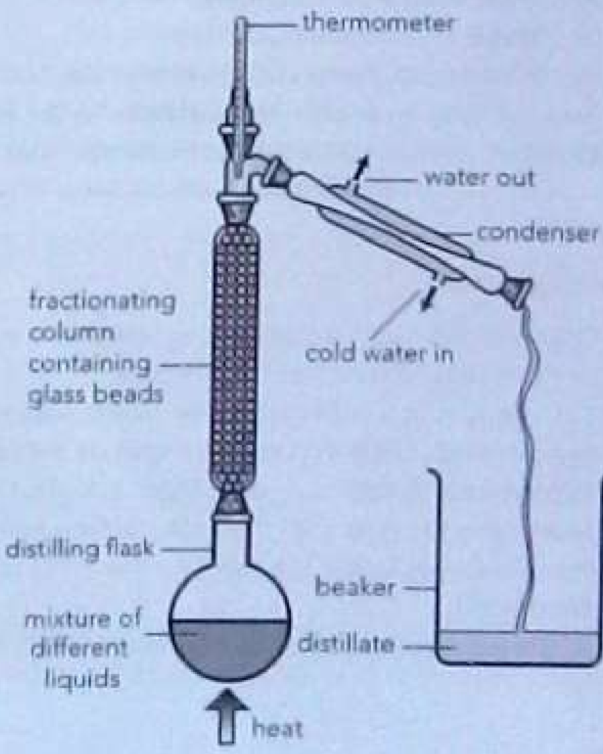


Figure 10.4 Fractional distillation

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For example, if a mixture of liquids A and B is distilled in this manner, and liquid A has a boiling point of 65 °C while that of liquid B is 75 °C, then, once the mixture reaches 65 °C, the vapours of liquid A will continue to move through the fractionating column without condensing.

Liquid B's vapours will continue to condense and drip back into the flask, while liquid A's vapours will move through to the condenser, to be collected in the beaker or flask on the other side.

In fractional distillation, the liquids are called **fractions**, so the first **fraction** that is collected is always the fraction with the lower boiling point.

This method gives a better separation of liquids than simple distillation.

Experiment 10.2

Aim: To separate a mixture of ethanol and water using fractional distillation

Materials: a round-bottomed flask, a fractionating column, a condenser, a thermometer, a beaker, a clamp stand, rubber tubing, a Bunsen burner, a 50   50 solution of ethanol and water

Procedure

1. Carefully arrange the apparatus as shown in Figure 10.3.
2. Turn on the water tap to allow the fraction to be cooled.
3. Turn on the burner and let the liquid start to evaporate and drip back.
4. Note when the first drop of liquid drips from the condenser. Record the temperature.
5. Turn off the burner when the thermometer reading starts rising again.

Results

You should find that some of the liquid remains in the round-bottomed flask and that some of the liquid is in the beaker on the other side. However, are the two liquids pure fractions of the mixture?

Questions

1. Answer the following questions about the first fraction.
   a) What was its boiling point?
   b) Was it ethanol or water?
   c) How do you know the identity of the first fraction?
2. Because there were only two fractions in the mixture, we could end the experiment where we did. However, what could we do to make sure that the second fraction is pure?

Summary

- Simple distillation can be used to separate a mixture of two liquids with different boiling points, or to separate a solute from a solvent.
- The liquid that is collected in the beaker after passing through the condenser is called the distillate.
- Fractional distillation is used to separate a mixture of two liquids that have similar boiling points.
- In fractional distillation, the liquids are called fractions, so the first fraction that is collected is always the fraction with the lower boiling point.
- Fractional distillation is a more precise method of separating liquid mixtures than simple distillation.
- A volatile liquid is one that evaporates easily under normal circumstances.

Glossary

distillate – the part of the mixture that is separated from the mixture and passes through the condenser during simple distillation

fraction – one of the components in a mixture that can be separated by fractional distillation

fractional distillation – the process of separating mixtures of liquids by means of their different boiling points

miscible – liquids that mix together easily to form a uniform mixture

simple distillation – a separation method where a liquid is separated from a soluble solid by heating the solution and collecting the vapour as a distillate

volatile – evaporates easily

Revision questions

1. Which method would be best to purify a sample of drinking water?
   - **A** evaporation
   - **B** condensation
   - **C** simple distillation
   - **D** filtration (1)
2. Which method would be best to separate pure water from a salt solution without losing the water?
   - **A** evaporation
   - **B** filtration
   - **C** simple distillation
   - **D** fractional distillation (1)
3. Explain why round glass beads instead of square glass beads are used in a fractionating column. (3)
4. Hexane and toluene are organic chemicals that are commonly used as solvents. Hexane has a boiling point of 69 °C and toluene has a boiling point of 111 °C. Which method of separation would a chemist use to separate a mixture of these two liquids? Give a reason for your answer. (2)
5. A graph of temperature versus time for a fractional distillation experiment shows the temperature remained constant for as long as the first fraction was boiling off. Explain why the temperature did not increase steadily, even though the burner was on the whole time. (2)
6. Draw a simple sketch to show the apparatus used in simple distillation. (6)

TOTAL: 15

Unit 11 Matter

Objectives

- Describe the arrangement of metals and non-metals in the Periodic table.
- Name the different subatomic particles.
- State the relative charges and masses of the different subatomic particles.
- State the relative position of the subatomic particles within the atom.
- Name the first 20 elements in the Periodic table, stating their symbols.
- Write the electronic configuration of the first 20 elements.
- Describe ionic and covalent bonding.
- Define the terms 'relative mass' and 'mass number'.
- Explain what the proton number and the atomic number indicate.
- Calculate the number of neutrons for an atom from given data.
- Define the term 'isotope'.
- Define Avogadro's number (N_A).
- Point out the relationship between mole and relative molecular mass (M_r) as well as relative atomic mass (A_r).
- Calculate the empirical formula and molecular mass of any given element.
- Calculate the concentration of solutions in mole/dm^3 and g/dm^3

Introduction

Even though the idea of matter was known for a very long time, no one was able to explain it in a concrete and tested way until Dalton suggested the existence of particles (or atoms) in all matter. Dalton's writings describe his ideas about the nature of an atom. These are the ideas that make up the atomic theory. This theory is based on the following assumptions:

1. Matter is made up of small particles called atoms.
2. Atoms cannot be divided any further and atoms cannot be created or destroyed.
3. The atoms of a particular substance are identical, that is, they have the same properties.
4. The properties of atoms of two different substances are dissimilar.
5. In a chemical reaction, atoms are rearranged.

The different subatomic particles

The structure of an atom

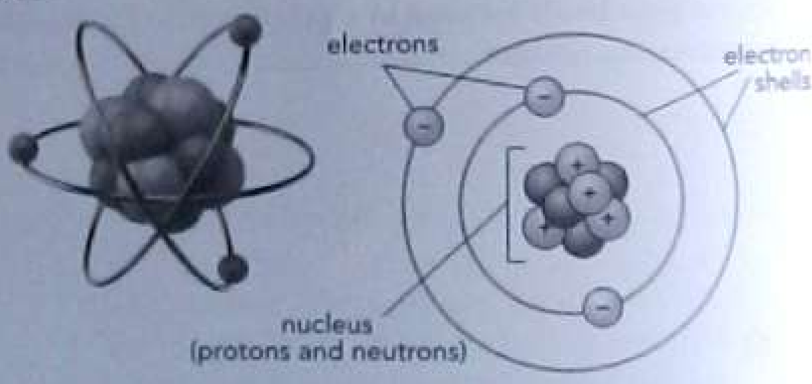


Figure 11.1 3D model (left) and diagram (right) of an atom

Atoms are too small for us to see with the naked eye, but scientists have been able to find out a great deal about them. Every atom consists of a nucleus (itself consisting of neutrons and protons) surrounded by orbiting electrons. Figure 11.2 shows the structure of an atom and the relative charges and masses of these particles.

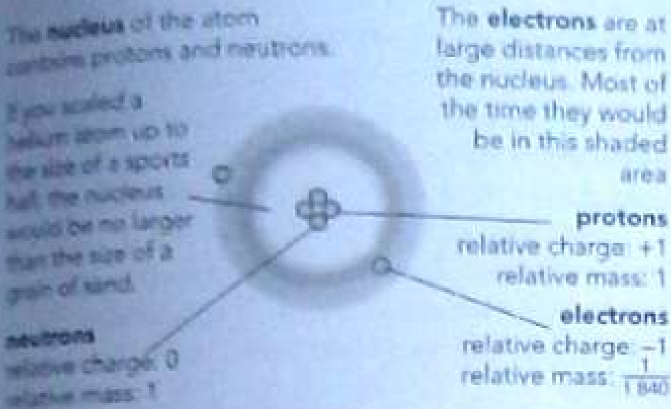


Figure 11.2 A highly magnified diagram of an atom

Nearly all the mass of an atom is concentrated in the nucleus, that is, the part consisting of protons and neutrons. The protons carry a positive charge. The neutrons have no charge at all. Therefore, the nucleus is positively charged.

The electrons orbit the nucleus in different energy levels or **electron shells**. Each shell can hold a limited number of electrons.

In an atom, the number of electrons is the same as the number of protons, so an atom is said to be electrically neutral.

Scientists have determined the actual masses of the subatomic particles:

Subatomic particle	Mass (g)	Mass divided by mass of one proton
proton	1.6727×10^{-24}	$\frac{1.6727 \times 10^{-24}}{1.6727 \times 10^{-24}} = 1$
neutron	1.6750×10^{-24}	$\frac{1.6750 \times 10^{-24}}{1.6727 \times 10^{-24}} = 1.001 = 1$
electron	9.110×10^{-28}	$\frac{9.110 \times 10^{-28}}{1.6727 \times 10^{-24}} = 0.00054 = \frac{1}{1840}$

As you can see, the mass of protons are very near to the mass of neutrons, while that of electrons is much, much smaller. The **relative mass** of each subatomic particle (as seen in Figure 11.1) is calculated by dividing the mass of each by the mass of one proton.

Exercise 11.1

1. Which part of an atom is the heaviest?
2. Why is an atom said to be neutral?
3. Copy and complete the table below:

Particle	Symbol	Charge
	p	
neutron		
		negative

4. Draw a simple diagram of the structure of an atom. Label the subatomic particles and any other features of the atom.

Atomic number

The number of protons in an atom is called its **atomic number** or proton number. Each element has a different number of protons. The equation below is true for any atom:

atomic number = number of protons

Mass number

The **mass number** is the total number of *protons* and *neutrons* in the nucleus of the atom. We also call protons and neutrons **nucleons**, because they are found together in the nucleus of atoms. This equation states the relation between the number of nucleons and the mass number:

mass number = number of protons + number of neutrons

We can show this information very simply for any atom. For example, Figure 11.3 shows this information for carbon. Carbon has six protons and six neutrons; therefore the mass number is 12. The mass number is always written above the atomic number in **nuclide notation**.

$${}^{12}_{6}\mathrm{C}$$

Figure 11.3 The nuclide notation for carbon

Example

Potassium has a mass number of 39 and an atomic number of 19.
How many neutrons are there in one atom of potassium?

Answer

Mass number = number of protons + number of neutrons = 39

Atomic number = number of protons = 19

Therefore, number of neutrons = 39 − 19 = 20

Exercise 11.2

Determine the number of neutrons for each of the following atoms, given their atomic and mass numbers:

Element	Atomic number	Mass number	Number of neutrons
1. calcium	20	40	
2. iron	26	56	
3. sodium	11	23	
4. zinc	30	65	

Isotopes

The number of neutrons in atoms of the same element is not always the same. For example, there are three types of carbon atoms: carbon-12, carbon-13 and carbon-14. They all have the same number of protons, because all carbon atoms have six protons. However, they have different numbers of neutrons. These different atoms of carbon are called **isotopes**.

The three isotopes of carbon are shown in Figure 11.4. The diagram shows that isotopes are named according to their mass numbers.

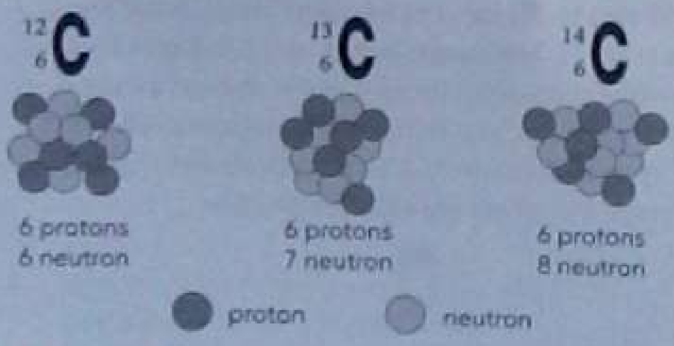


Figure 11.4 The nuclei of the three isotopes of carbon: carbon-12, carbon-13 and carbon-14

Isotopes have the same atomic number, but because they have different numbers of neutrons, their mass numbers are different. The fact that they have different numbers of neutrons does not make a difference to the way they react during chemical reactions. The chemical properties of an atom depend on the number of electrons and on how the electrons are arranged. This will be the same for the isotopes of an element.

Oxygen has a number of isotopes, but only three of them are relatively stable: ^{16}O, ^{17}O and ^{18}O. The lightest isotope, namely ^{16}O, is by far the most common in the Earth's atmosphere, at 99.8%.

Note that we have left out the atomic number in the nuclide notation of these three isotopes, because the element is known. The nuclide notation for isotopes often leaves out the atomic number.

Chlorine also has a number of isotopes, but only two of them, namely ^{35}Cl and ^{37}Cl, are stable.

Exercise 11.3

1. Complete the following sentences.
   An atom is composed of negatively charged __a)__, positively charged __b)__ and __c)__. The nucleus contains __d)__ and __e)__, with both particles having a relative mass of about __f)__. The atomic number refers to the number of __g)__ in the nucleus, and the mass number refers to the number of __h)__. Isotopes of a substance have the same __i)__ number but different __j)__ numbers.
2. How many protons and neutrons are there in each isotope of oxygen?

   a) $^{16}_{8}O$ b) $^{17}_{8}O$ c) $^{18}_{8}O$

Electronic configuration

Atoms are electrically neutral. This means that the number of positive protons is balanced by the number of negative electrons. We can show this relation in the following equation:

number of electrons = number of protons

The electrons of an atom are arranged in a series of energy shells around the nucleus.

This arrangement is called its **electronic configuration**. Each energy shell can only hold a certain number of electrons. The energy shells (or electron shells) become larger the further they are from the nucleus. The larger a shell, the more electrons it can hold.

- **Energy shell 1:** This shell is closest to the nucleus; it can hold a maximum of 2 electrons.
- **Energy shell 2:** This shell can hold a maximum of 8 electrons.
- **Energy shell 3:** This shell's maximum is also 8.
- **Energy shell 4:** The maximum here is 18.

How to work out the electronic configurations

We will use sodium as an example.

Step 1: Look up the atomic number in the Periodic table. The atomic number for sodium is 11.

Step 2: The atomic number gives the number of protons and thus the number of electrons. So, there are 11 protons as well as 11 electrons in a neutral sodium atom.

Step 3: Arrange the electrons in shells. Always fill up the inner (lower energy) shells before going on to an outer one.

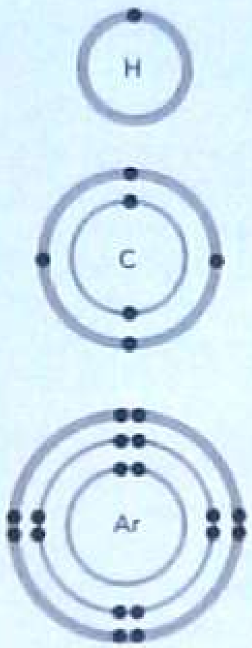
Step 4: In sodium, the electrons are arranged as two (2) in the first shell, eight (8) in the second and one (1) in the third. This is written as 2,8,1. When you have finished, always check that the electrons add up to the right number. Here it is 11.

Electronic configuration diagrams

We can draw electronic configuration diagrams of the atoms of elements to show how many electrons there are in any of their atom's shells.

The electronic configuration diagrams of hydrogen, carbon and argon are shown in Figure 11.5.

Can you see the relationship between the diagrams and the electronic configurations of these elements in the table at the bottom of this page?



The electronic configuration of hydrogen is very simple. There is only one electron to place in the first energy shell closest to the nucleus.

Carbon's six electrons are arranged in the first two energy shells.

Argon has 18 electrons to be placed. They use up all the space in the first three shells.

Figure 11.5 Electronic configuration diagrams of hydrogen, carbon and argon

The table below shows the electronic configurations of the first 20 elements in the Periodic table.

hydrogen 1								helium 2
lithium 2,1	beryllium 2,2		boron 2,3	carbon 2,4	nitrogen 2,5	oxygen 2,6	fluorine 2,7	neon 2,8
sodium 2,8,1	magnesium 2,8,2		aluminium 2,8,3	silicon 2,8,4	phosphorus 2,8,5	sulphur 2,8,6	chlorine 2,8,7	argon 2,8,8
potassium 2,8,8,1	calcium 2,8,8,2	← ... 10 more elements ... →						

The significance of the electronic structure of atoms

The electronic configuration of an atom is very important because the number of electrons in the outmost shell of an atom determines the chemical properties of an element, including how it joins (forms bonds) with other elements.

There are a group of elements that are called the **noble gases**. These gases are the elements helium, neon, argon, krypton, xenon and radon. These elements have eight (8) electrons in their outermost shell (except helium, which has two (2)). These shells are often thought of as being full shells. This means that these gases are almost completely **inert** or nonreactive. In fact, the first three noble gases, that is, helium, neon and argon, do not react with anything. We link this lack of reactivity to their electron structures. A full outermost shell makes these elements stable and inert.

Exercise 11.4

1. Draw up a table with three columns. In the first column, write the names of the first 20 elements in the Periodic table. In the second column, write each element's chemical symbol. In the third column, write each element's electronic configuration.
2. Draw the electronic configuration diagrams for the following elements.
   a) lithium
   b) helium
   c) silicon
   d) fluorine
   e) sodium

Metals and non-metals in the Periodic table

For centuries scientists have been trying to arrange the 118 elements into some sort of order. Over the years, different methods have been suggested. These methods have helped scientists develop the modern Periodic table that we use today.

On the following page is the modern Periodic table of the elements.

Work carried out by a number of scientists pointed towards an arrangement of the elements by proton number (atomic number) as making the most sense. In the modern Periodic table, all the elements are arranged in order of increasing proton number. Elements with similar chemical properties are in the same columns or **groups**. Some of the groups have been given names:

- Group 1: The alkali metals
- Group 2: The alkaline earth metals
- Group 17: The halogens
- Group 18: The noble gases

The horizontal rows are called **periods**, which are numbered from 1 to 7. Between Group 2 and Group 13 there is a block of elements called the transition metals. This block contains well-known metals such as copper, iron, nickel, zinc and chromium.

From this brief description, we can see that the metals are mostly found on the left and in the middle of the Periodic table, and the other, non-metallic elements are found mostly on the far right. We can also see that there are far more metals than non-metals listed in the Periodic table.

In fact, the thick black lines in Figure 11.6 indicate the division between metals and non-metals. The black lines indicate the position of the **metalloids**, which are elements that have properties that lie between those of the metals and non-metals.

The electronic structure of elements and the Periodic table

The table at the top of the right-hand column shows the electronic structure of the first three elements of Group 1. Notice that, in each case, the outer shell contains only one electron.

Group 1

Element	Symbol	Proton number	Electronic structure
lithium	Li	3	2,1
sodium	Na	11	2,8,1
potassium	K	19	2,8,8,1

Periodic Table of the Elements

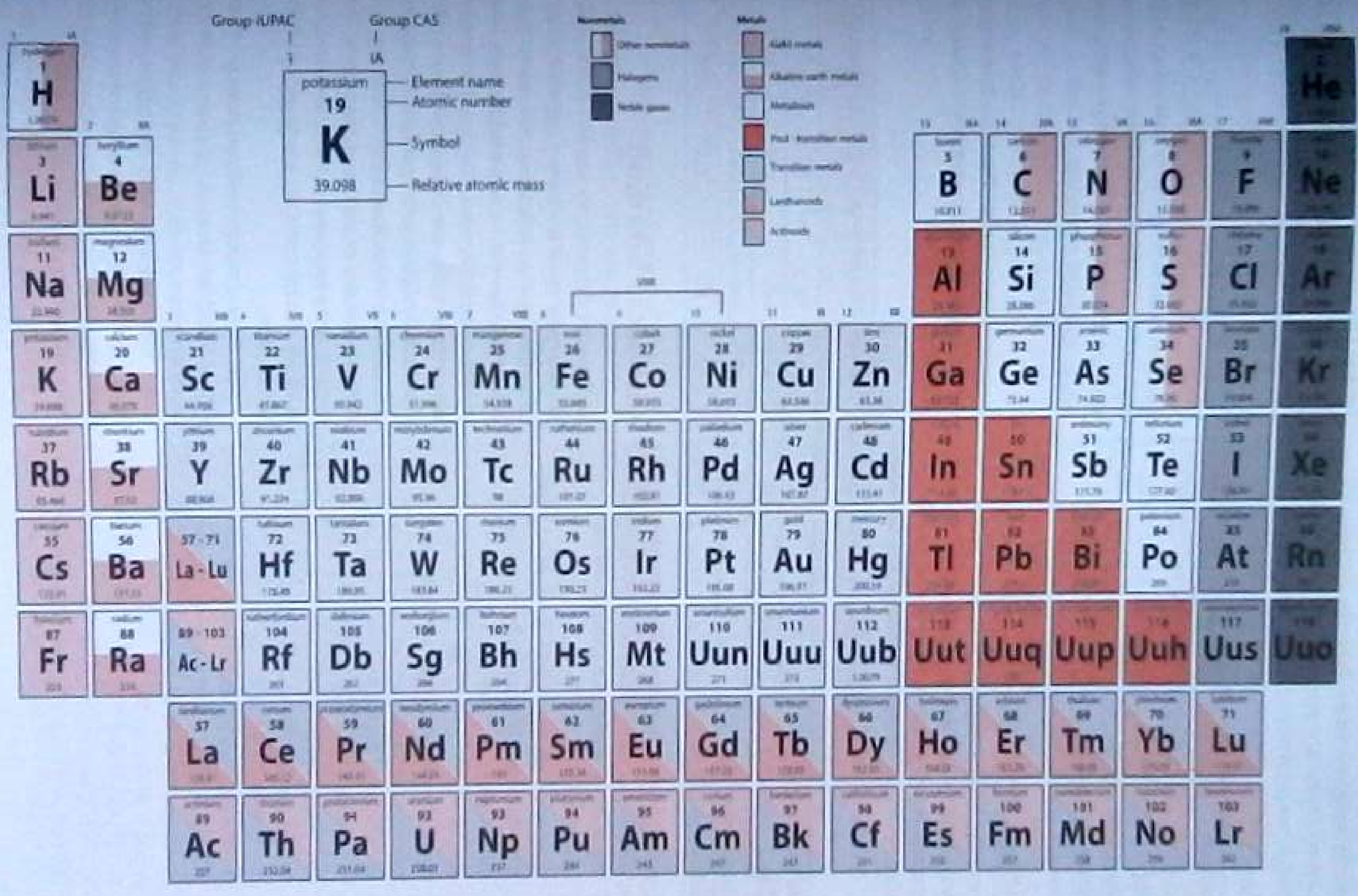


Figure 11.6 The Periodic table of the elements

The following two tables show the electron structures of the first three elements of Group 2 and Group 17 respectively.

Group 2

Element	Symbol	Proton number	Electronic structure
beryllium	Be	4	2,2
magnesium	Mg	12	2,8,2
calcium	Ca	20	2,8,8,2

Group 17

Element	Symbol	Proton number	Electronic structure
fluorine	F	9	2,7
chlorine	Cl	17	2,8,7
bromine	Br	35	2,8,18,7

It is the outermost electrons that are mainly responsible for the chemical properties of an element. Elements in the same group therefore have similar chemical properties.

Periodic trends

One of the main trends in the Periodic table is the change from metals to non-metals and physical properties across a period. Melting and boiling points, as well as density are some of the physical properties that change. The table below shows the change in physical properties across Period 3 elements:

	Sodium	Magnesium	Aluminium	Silicon	Phosphorus	Sulphur	Chlorine	Argon
Electron structure	2,8,1	2,8,2	2,8,3	2,8,4	2,8,5	2,8,6	2,8,7	2,8,8
Melting point (°C)	98	650	659	1 410	448	119	–101	–119
Boiling point (°C)	897	1 117	2 447	2 677	294	444	–34	–186
Density (g/cm³)	0.97	1.74	2.70	2.40	1.82	2.07	0.56	0.40

Exercise 11.5

1. What do elements in a group have in common?
2. How many electrons does an element with the following atomic number have in its outer shell?
   a) 14 b) 19
3. Name the elements that are found in the following positions:
   a) Group 1, Period 3
   b) Group 13, Period 2
   c) Group 17, Period 2
   d) Group 17, Period 3
   e) Group 2, Period 4
   f) Group 14, Period 2
4. Which statement about the element with atomic number 20 is correct?
   A. It is in Group 14.
   B. It is in Group 2.
   C. It is a transition metal.
   D. It is in Group 17 and is a halogen.

Chemical bonding

Sodium is a dangerously reactive metal. It is stored in oil to prevent it from reacting with air or water. Chlorine is a very poisonous and reactive gas. However, table salt, or sodium chloride, is safe to eat in small amounts. So, combining these elements to make salt obviously changes them significantly. Salt is a compound. A compound is a chemical combination of two or more elements. Salt is composed of units combining one atom of sodium and one atom of chlorine. Water is another example of a compound. It is made up of hydrogen and oxygen.

To make a compound you have to chemically join or **bond** the atoms of different elements together. Elements that can react have incomplete shells. When reacting with each other, atoms will donate and receive electrons in order to form **ionic compounds** or they will share electrons to form **molecular compounds**.

Ionic bonding

In this section, you will learn what ionic bonding is. We will look at the formation of sodium chloride, magnesium oxide and sodium oxide as examples.

What is ionic bonding?

Ionic compounds are formed when atoms lose and gain electrons and so become **ions** attracting each other and binding together. An ion is an atom that has too many or too few electrons to be neutral. Ions of opposite charges attract one another and so form ionic bonds. See the example in Figure 11.7 where the compound is held together by the strong electrical attraction between positive and negative ions.

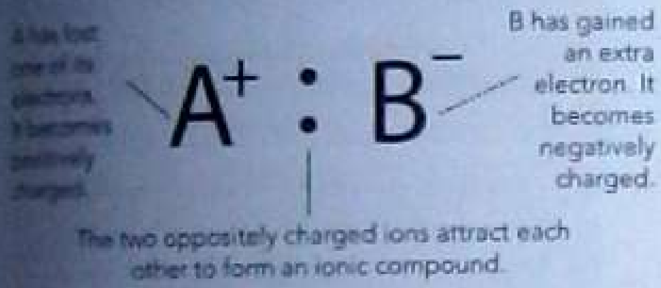


Figure 11.7 A simple example of ionic bonding

Ionic compounds are formed between metals and non-metals.

Metals form positive ions (**cations**), because they lose electrons and so become positively charged. Non-metals form negative ions (**anions**), because they gain electrons and become negatively charged. The electrons that are involved in all types of bonding are called **valence electrons**. They are only found in the outermost shell of atoms. Therefore, the **valency** of an element is the number of electrons an atom must *lose* or *gain*, either completely or by sharing, to obtain a noble gas configuration.

Metals in Group 1 of the Periodic table have a valency of 1, because they lose one electron to become cations. Group 2 elements have a valency of 2, and Groups 13 and 14 elements have valencies of 3 and 4 respectively. Group 15 elements can gain three electrons to become anions so that their valency is 3. Group 16 elements gain two electrons so that their valency is 2. Group 17 elements have a valency of 1.

When we show bonds (ionic or covalent), we use dot-and-cross diagrams, where dots and crosses represent electrons. The difference between the electrons we draw as dots and those we draw as crosses is that they come from different atoms.

Bonding in sodium chloride

Sodium has one electron in its outer shell. It can attain a full number of electrons in its outer shell and thus become stable by losing this one electron. It now becomes a sodium ion that carries a positive charge (as it has lost an electron).

A chlorine atom has 17 electrons. It attains a noble gas configuration by gaining an extra electron. It now becomes a chloride ion. The chloride ion gains an electron from the sodium atom, which loses an electron.

The two ions have opposite charges and so they attract each other. The **electrostatic force** of attraction between the ions is very strong. The bond between the two ions is called an **ionic bond** or an electrovalent bond. The compound that is formed is called an ionic compound. Its formula is Na^+Cl^- or, more simply, NaCl as seen below:

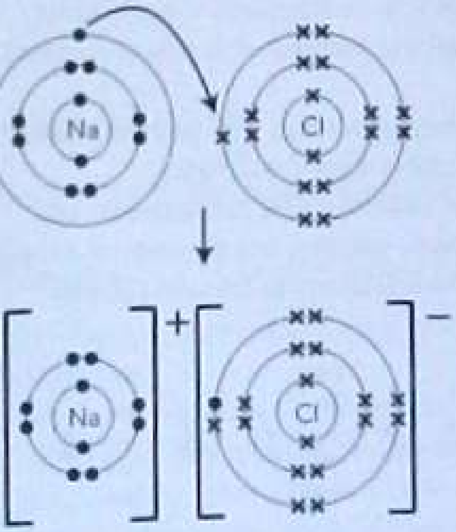


Figure 11.8 Ionic bonding in sodium chloride

Bonding in magnesium oxide

Magnesium (a metal from Group 2) has two electrons in its outer shell, so it can become stable by losing these two valence electrons. It therefore becomes a magnesium ion with a charge of 2+.

An oxygen atom has 16 electrons. It needs another two valence electrons in order for it to attain a stable outer shell. In bonding with magnesium, both ions thus achieve a full outer shell configuration. The ionic compound formed is MgO.

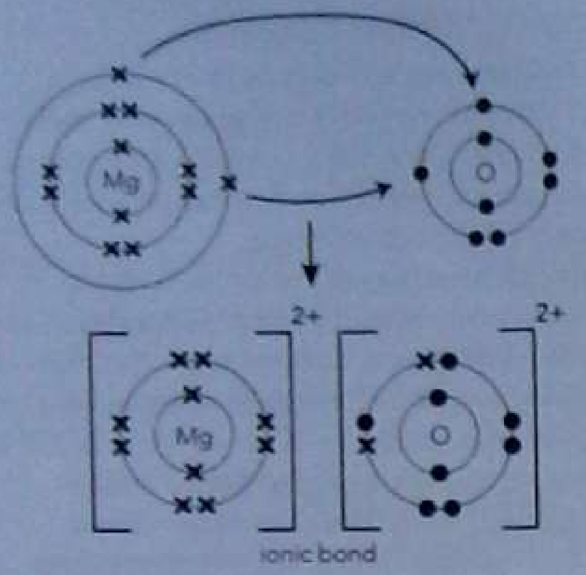


Figure 11.9 Ionic bonding in magnesium oxide

Bonding in sodium oxide

In sodium chloride and magnesium oxide, the valency of both ions in the bond was the same. Thus, one metal ion bonded with one non-metal ion.

But what happens when the valencies differ? Sodium oxide offers a good example:

An atom of sodium metal needs to lose one electron to achieve stability, but an atom of oxygen needs to gain two electrons to achieve stability.

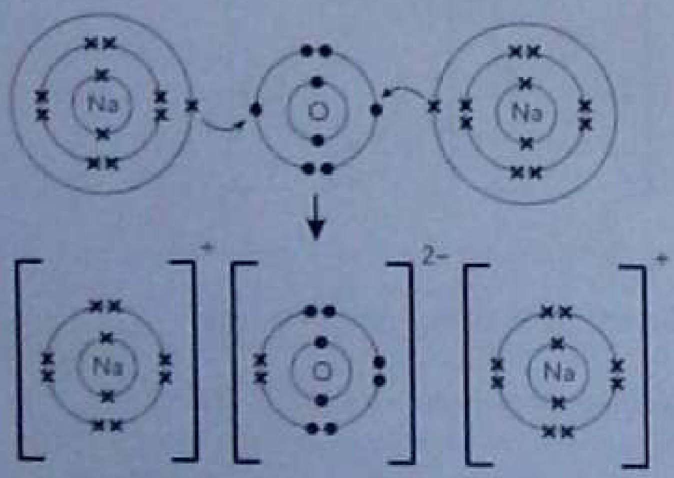


Figure 11.10 Ionic bonding in sodium oxide

One ion of oxygen therefore needs to bond with two ions of sodium in order for all ions to achieve stability. The ionic compound formed is therefore Na_2O.

Properties of ionic compounds

The properties of ionic compounds include:

1. Ionic compounds are usually solids at room temperature.
2. Ionic compounds have high melting and boiling points because of the strong forces that hold the molecules together.

   The table below shows the melting and boiling points of a few ionic compounds:

	NaCl	KBr	NaI	$MgCl_2$
Melting point (°C)	808	735	662	714
Boiling point (°C)	1 465	1 435	1 302	1 420

3. They conduct electricity when molten or in aqueous solutions. This happens because the forces of attraction between the ions are weaker and so the ions are free to move.
4. They mainly dissolve in water to form aqueous solutions.

Exercise 11.6

1. Why are noble gases inert (nonreactive)?
2. What types of atoms form an ionic compound?
3. Describe how the bonding occurs between:
   a) aluminium and chlorine
   b) potassium and oxygen
4. List three properties of ionic compounds.
5. Draw dot-and-cross diagrams to show the bonding in the following:
   a) calcium oxide
   b) potassium oxide
6. Why does the calcium ion have a charge of +2?

Covalent compounds

In this section on covalent compounds, you will learn about **covalent bonds** by looking at hydrogen, chlorine and water molecules.

What is a covalent bond?

In a **covalent bond**, the two atoms share a pair of electrons. The force that holds the two atoms together is due to the attraction between the shared pair of electrons and the positive nucleus of each atom. You can see an example of this in Figure 11.11.

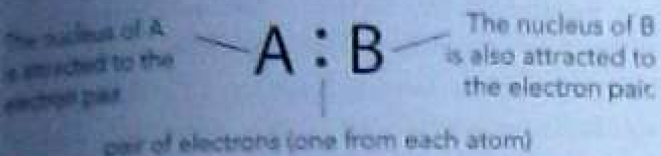


Figure 11.11 A covalent bond

Bonding in a hydrogen molecule

Figure 11.12 shows the covalent bonding in a hydrogen molecule. A hydrogen atom has only one electron. Remember that it has only one shell which can hold a maximum of two electrons. Therefore, it needs one extra electron to attain a noble gas configuration. When two hydrogen atoms react together, the electrons in the atoms are shared to form a covalent bond. We can represent a hydrogen molecule as H–H. The formula for a hydrogen molecule is therefore H_2.

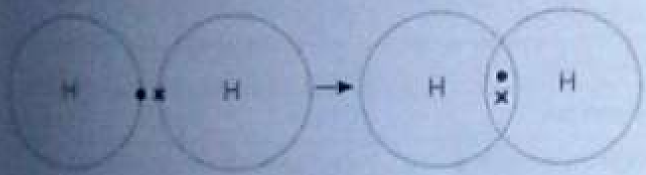


Figure 11.12 Covalent bonding in a hydrogen molecule

Bonding in a chlorine molecule

All the elements in Group 17 have seven electrons in their outermost shells. Therefore, each atom needs one more electron to achieve stability. However, if two reacting chlorine atoms each allow the other atom to share one of its electrons, then both achieve stability. The formula for chlorine gas is Cl_2.

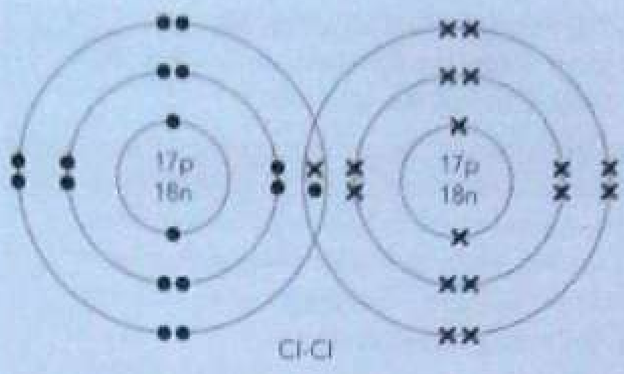


Figure 11.13 Covalent bonding in a chlorine molecule

Bonding in a water molecule

An oxygen atom has six electrons in its outermost shell. It therefore needs to gain or share another two in order to achieve stability.

Hydrogen atoms each have only one electron in their outermost (or only) shells. Therefore, two hydrogen atoms have to bond covalently with one oxygen atom to form a water molecule.

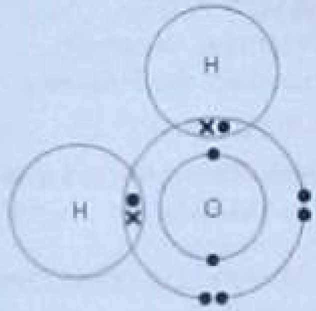


Figure 11.14 Covalent bonding in a water molecule

Properties of covalent compounds

The properties of covalent compounds include the following:

1. They are usually gases or liquids.
2. They have low melting and boiling points, because the forces that hold the molecules together are weak. The table below shows the melting and boiling points of a few covalent compounds.

	H_2	CH_4	C_2H_5OH	O_2	H_2O
Melting point (°C)	–259	–182	–114	–218	0
Boiling point (°C)	–253	–161	78	–183	100

3. They do not conduct electricity.
4. They are generally insoluble in water, but soluble in organic solvents.

Exercise 11.7

1. Give the name for the type of bond that occurs when elements share electrons.
2. Draw dot-and-cross diagrams to show the following molecules.
   a) oxygen (O_2)
   b) hydrogen chloride (HCl)
   c) methane (CH_4)
3. Give three physical properties of covalent compounds.

Stoichiometry and the mole concept

The atomic mass of an element represents the average mass of one atom of that element expressed in atomic mass units (amu).

When we express the atomic masses of elements in grams, we can make the following conclusion:

The atomic mass in grams represents the same number of atoms for each element.

Scientists used this information long before they knew what this number was. In this unit, you will learn what this number is and how big it is.

Equations

We use chemical equations to represent the reactions between substances. For example:

iron + sulphur → iron sulphide, or,
using symbols, Fe + S → FeS

The symbols and numbers in the equation represent the relative number of atoms that combine in a reaction. So, in the example above, one atom of Fe combines with one atom of S to give one molecule of FeS.

To write a chemical equation, you have to know the formulae for the reactants and products.

Determining the formulae of compounds

The electrons used in ionic or covalent bonding are the valence electrons and they are in the outermost energy shell. Valency refers to the number of valence electrons an atom loses or gains when forming a chemical bond.

Recall that the metals in Group 1 have a valency of one as they lose one electron when they become cations. Group 2, Group 13 and Group 14 elements have valencies of two, three and four respectively. Group 15 elements gain three electrons to become anions so that their valency is three. Group 16 elements have a valency of two and the halogens in Group 17 have a valency of one.

Some common ions are shown below.

Name	Cation (+)	Valency
ammonium	NH_4^+	1
copper(I)	Cu^+	1
copper(II)	Cu^{2+}	2
iron(II)	Fe^{2+}	2
iron(III)	Fe^{3+}	3

Name	Anion (–)	Valency
carbonate	CO_3^{2-}	2
chloride	Cl^-	1
cyanide	CN^-	1
dichromate	$Cr_2O_7^{2-}$	2
fluoride	F^-	1
hydrogen carbonate	HCO_3^-	1
hydroxide	OH^-	1
manganate(VII)	MnO_4^-	1
nitrate	NO_3^-	1
oxide	O^{2-}	2
phosphate	PO_4^{3-}	3
sulphate	SO_4^{2-}	2
sulphide	S^{2-}	2
sulphite	SO_3^{2-}	2
thiosulphate	$S_2O_3^{2-}$	2

Naming a compound

The name of an ionic compound comes from the cation and the anion forming the compound, as you can see in the table below.

Ions in compound	Name of compound	Formula
$Na^+ + Cl^-$	sodium chloride	$NaCl$
$Ca^{2+} + O^{2-}$	calcium oxide	CaO
$Li^+ + O^{2-}$	lithium oxide	Li_2O
$K^+ + SO_4^{2-}$	potassium sulphate	K_2SO_4

Ionic equations

In this section, we look at the types of equation that are used to represent reactions in solution. So far you have written molecular equations as in the example below:

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

There are several reactions that involve solutions or compounds in solution form. In these reactions, the ions in the solution play different roles in the chemical reaction.

Some ions become passive while others are actively involved in forming the products. You can clearly see the role of each ion in the reaction when all ions are written down as in the example below.

When you are instructed to write the **net ionic equation** for a reaction, cancel the ions that are unchanged on both sides (they do not take part in the chemical reaction). The remaining ions take part in the chemical equation.

An ionic equation shows which ions undergo change in a reaction. Let us look at an example.

Example

Hydrochloric acid reacts with sodium hydroxide to give sodium chloride and water:

$$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$$

Write a net ionic equation for the reaction.

Answer

$HCl(aq)$, $NaOH(aq)$ and $NaCl(aq)$ exist as free ions in solution (remember ionic compounds dissolve to form free hydrated ions in solution), so we can write them like this:

$$\underbrace{H^+(aq) + Cl^-(aq)}_{\text{acid}} + \underbrace{Na^+(aq) + OH^-(aq)}_{\text{sodium hydroxide}} \rightarrow$$

$$\underbrace{Na^+(aq) + Cl^-(aq)}_{\text{sodium chloride}} + \underbrace{H_2O(l)}_{\text{water}}$$

When we cancel the ions that are found on both sides (they are unchanged), we obtain the net ionic equation:

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$$

Exercise 11.8

Write the ionic equation for each reaction:

1. $NaCl(aq) + AgNO_3(aq) \rightarrow AgCl(s) + NaNO_3(aq)$
2. $BaCl_2(aq) + H_2SO_4(aq) \rightarrow BaSO_4(aq) + 2HCl(aq)$
3. $CuSO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + Cu(OH)_2(s)$

Relative atomic mass and formula mass

Because the mass of an atom is very small, a scale of atomic mass units was developed to compare the masses of different atoms. This scale compares the mass of all atoms to that of an atom of carbon-12, which is assigned a mass of exactly 12.00 unified atomic mass units (u).

Therefore, we find that the **relative atomic mass** (A_r) is a ratio and has no units:

$$A_r = \frac{\text{average mass of an atom of element X}}{\frac{1}{12} \times \text{the mass of a carbon-12 atom}}$$

You can measure the masses of compounds using the same carbon-12 scale. When talking about compounds, we use the term **relative molecular mass** (M_r), which is sometimes also called relative formula mass. Relative molecular mass is the mass of one molecule of substance. Just like the mass of a car is the sum of the masses of all its component parts (wheels, engine, battery, and so on), the mass of a molecule is the sum of all its component atoms.

If you know the formula of a molecule, you can find the relative mass of that molecule.

Example

Find the relative formula mass of sulphuric acid.

Answer

Formula: H_2SO_4
Mass of 2 × hydrogen atoms: 2 × 1 = 2
Mass of 1 × sulphur atom: 1 × 32 = 32
Mass of 4 × oxygen atoms: 4 × 16 = 64
Total: 2 + 32 + 64 = 98
The relative formula mass of sulphuric acid is 98.

Exercise 11.9

Work out the relative molecular or formula mass of each compound.

1. NaOH
2. HCl
3. $CuSO_4$
4. MgO
5. $FeCl_3$

The mole and Avogadro's number (N_A)

Often chemists work with samples that contain enormous numbers of atoms and so they use a special unit to describe very large numbers of atoms. Using a unit to describe a particular number of objects is not new, for example, one dozen represents 12 objects.

The unit chemists use is the **mole**. A mole is a measure of an amount of substance. One mole of molecules or one mole of atoms of a substance has a mass in grams that is the same as the relative atomic mass or relative molecular mass. For example, carbon dioxide (CO_2) has the following relative molecular mass: 12 + 16 + 16 = 44. So, one mole of carbon dioxide has a mass of 44 g.

In general, one mole of atoms has a mass that is equal to the atomic mass of the atom and one mole of molecules has a mass that is equal in number to the molecular mass of the substance. One mole of a compound is called a **molar mass**. A molar mass is the same as the **formula mass**.

The number of particles (atoms or molecules) in one mole of anything is the same.

The number is 6.023×10^{23}, and it is defined as the number of atoms in 12 g of carbon-12. It is called **Avogadro's number** (or the Avogadro constant) with symbol N_A.

1 mole = 6.023×10^{23} particles

We use the following equation in calculations involving moles and relative atomic or formula masses:

$$\text{number of moles} = \frac{\text{mass}}{\text{mass of one mole}}$$

In symbols: $n = \frac{m}{M_r}$

Example

Calculate the mass of:

1. one water molecule (H_2O)
2. one mole of water molecules.

Answer

1. $H_2O - (2 \times 1) + 16 = 18$
2. $n = \frac{m}{M_r}$ therefore $m = M_r \times n = 18 \times 1 = 18$ g

   One mole of molecules has a mass equal to the molecular mass. So, a mole of water molecules has a mass of 18 g.

Example

Calculate the number of moles in 6 g of carbon.

Answer

$n = \frac{m}{M_r} = \frac{6}{12} = 0.5$ mol

OR

12 g of carbon represents one (1) mole.
6 g of carbon represents x moles.
Therefore, $x = 6 \times \frac{1}{12} = 0.5$ moles

Example

What is the number of atoms in 4 g of carbon?

Answer

$n = \frac{m}{M_r} = \frac{4}{12} = 0.33$ mol

One mole contains 6.02×10^{23} atoms, therefore 0.33 moles contains $0.33 \times 6.02 \times 10^{23}$ $= 2.0 \times 10^{23}$ atoms.

Exercise 11.10

1. Calculate the number of moles in:
   a) 3 g of carbon
   b) 24 g of calcium
   c) 54 g of silver
   d) 0.635 g of copper.
2. Calculate the number of atoms in:
   a) 1 g of calcium
   b) 12 g of magnesium
   c) 0.56 g of iron
   d) 0.004 g of helium.
3. Calculate the mass of the following:
   a) $5.0 \times 10^{[illegible]}$ atoms of sodium
   b) $1 \times 10^{[illegible]}$ atoms of potassium
   c) $1 \times 10^{[illegible]}$ atoms of copper.
4. Calculate the molar mass of each compound.
   a) $MgCl_2$
   b) C_2H_5OH
5. Calculate the number of moles in:
   a) 0.25 g of sodium carbonate
   b) 5.0 g of sodium hydroxide.

Using moles to find formulae

A formula gives important information about a compound. For example, the formula for water (H_2O) shows the following:

- Two atoms of hydrogen combine with one atom of oxygen to form a water molecule.
- Two moles of hydrogen atoms combine with one mole of oxygen atoms to form one mole of water.
- 2×1 g of hydrogen atoms combine with 1×16 g of oxygen atoms.
- The mass of one mole of H_2O is $2\text{ g} + 16\text{ g} = 18\text{ g}$.

This means that, given the exact masses of atoms combined to produce a compound, you can work out the formula of the compound. Use the following steps:

Step 1: Convert the given masses of each atom into moles:

$$\text{number of moles} = \frac{\text{mass}}{\text{mass of one mole}}$$

Step 2: Write each mole in its simplest whole number ratio.

Example

Give the formula of the compound that is formed when 3.3 g of carbon is combined with 9.0 g of oxygen.

Answer

	C atom	O atom
Masses used	3.3 g	9.0 g
Number of moles	$\frac{3.3}{12} = 0.275$	$\frac{9}{16} = 0.56$
Simplest ratio	$\frac{0.275}{0.275} = 1$	$\frac{0.56}{0.275} = 2.04$
Formula	CO_2	

Experiment 11.1

Aim: To determine the formula of magnesium oxide

Materials: a crucible and lid, a tripod stand, a Bunsen burner, a balance, a strip of magnesium ribbon

Procedure

1. Weigh the crucible and lid on the balance and record the mass.
2. Place a piece of magnesium ribbon in the crucible and record the new mass.
3. Use the Bunsen burner to heat the crucible containing the magnesium for 5 minutes.
4. Open the lid of the crucible slightly, close the crucible, and then heat the crucible again quickly.
5. Repeat steps 3 and 4 until there are no more flares of smoke when you open the lid of the crucible.
6. Remove the lid of the crucible completely and heat the crucible quickly to convert all the magnesium into oxide.
7. Allow the crucible to cool, replace the lid and weigh the crucible with its contents.

Results

Below are theoretical results to show you how to work out the formula of magnesium oxide.

- Mass of crucible and lid: 23.1 g
- Mass of crucible, lid and magnesium: 25.5 g
- Mass of crucible, lid and product: 27.1 g
- Mass of magnesium used: (25.5 – 23.1) g = 2.4 g
- Mass of magnesium oxide produced: (27.1 – 23.1) g = 4.0 g
- Mass of oxygen combined with magnesium: (4.0 – 2.4) g = 1.6 g

Calculation:

	Mg atom	O atom
Masses used	2.4 g	1.6 g
Number of moles	$\frac{2.4}{24} = 0.1$	$\frac{1.6}{16} = 0.1$
Simplest ratio	$\frac{0.1}{0.1} = 1$	$\frac{0.1}{0.1} = 1$

Therefore, the formula is MgO.

Questions

1. Why did you keep the lid closed at first?
2. Why did you open the lid from time to time later until there were no more flares of smoke?
3. Which substance reacts with the magnesium in this experiment?
4. Write down a word equation for this reaction.
5. Use your results to calculate the formula of MgO.

The simplest formula of a substance is called its **empirical formula**. In Experiment 11.1, the empirical formula is one atom of magnesium combining with one atom of oxygen. The true formula for magnesium oxide is $(MgO)_n$ where n is a whole number. If $n = 1$, the formula becomes MgO, but if $n = 2$, the formula becomes Mg_2O_2. In the previous experiment, it was a coincidence that the formula was MgO, the same as the empirical formula, otherwise further experimental work would be needed to find the value of n.

Example

85.72 g of carbon combines with 14.28 g of hydrogen. If the relative formula mass of the compound formed is 28, what is its formula?

Answer

	C atom	H atom
Masses used	85.72 g	14.28 g
Number of moles	$\frac{85.72}{12} = 7.14$	$\frac{14.28}{1} = 14.28$
Simplest ratio	$\frac{7.14}{7.14} = 1$	$\frac{14.28}{7.14} = 2$
Empirical formula	CH_2	

The formula of the compound can be CH_2, C_2H_4, C_3H_6, C_4H_8, and so on, which is written as $(CH_2)_n$. To find the value of n, equate the formula $(CH_2)_n$ to the relative molecular mass of the compound.

$(CH_2)_n = 28$

$12n + 2n = 28$ (1 × carbon + 2 × hydrogen)

$14n = 28$

$n = \frac{28}{14}$

$= 2$

So, the formula of the compound is $(CH_2)_2$, which is C_2H_4.

Example

Chemical analysis shows that a certain compound contains 80% carbon and 20% hydrogen. Determine this compound's empirical formula.

Answer

To make the calculation easier, consider a 100 g sample of the compound:

	C atom	H atom
Masses used	80% of 100 g = 80 g	20% of 100 g = 20 g
Relative atomic mass (A_r)	12	1
Number of moles	$\frac{80}{12} = 6.67$	$\frac{20}{1} = 20$
Simplest ratio	$\frac{6.67}{6.67} = 1$	$\frac{20}{6.67} = 2.998 \approx 3$
Empirical formula	CH_3	

Exercise 11.11

1. A compound forms between 7.2 g of iron and 4.16 g of sulphur (when heated strongly together). It has a formula mass of 88. What is the molecular formula of the compound that is formed?
2. A chemist makes a mixture of 5 g of iron filings with 5 g of sulphur. The mixture is heated strongly until a compound with formula FeS is formed.
   a) Calculate the number of moles of each element in the mixture.
   b) Which substance is completely consumed in this reaction?
   c) Calculate the amount of the product that is formed in this reaction. Give your answer in grams.
   d) How much of the remaining substance is unreacted?
3. A compound contains 60% sulphur. The rest is oxygen. Determine the empirical formula for this compound.

Calculations that involve volumes

In reactions that involve solutions, it is more useful to measure the concentration in terms of moles dissolved in a particular volume rather than in terms of how much **solute** is dissolved in one litre of the solution.

$$\text{concentration} = \frac{\text{number of moles}}{\text{volume used in dm}^3}$$

Example

What is the concentration of a solution prepared by dissolving 2 g of calcium chloride in 250 mℓ of water?

Answer

250 mℓ = 0.250 dm^3

$$\text{Moles} = \frac{\text{mass}}{\text{formula mass}} = \frac{2}{111} = 0.018 \text{ moles}$$

$$\text{Concentration} = \frac{\text{number of moles}}{\text{volume}}$$

$$= \frac{0.018}{0.250} = 0.072 \text{ mol/dm}^3$$

Example

What mass of sodium carbonate is needed to prepare a solution of 0.2 mole per litre by using 250 mℓ of water?

Answer

$$\text{Concentration} = \frac{\text{number of moles}}{\text{volume}}$$

$$0.2 = \frac{\text{number of moles}}{0.250}$$

The number of moles is $0.2 \times 0.250 = 0.05$

Find the mass dissolved using the formula.

$$\text{Moles} = \frac{\text{mass}}{\text{formula mass}}$$

$$0.0005 = \frac{\text{mass}}{106}$$

$$\text{mass} = 0.0005 \times 106 \text{ g} = 5.3 \text{ g}$$

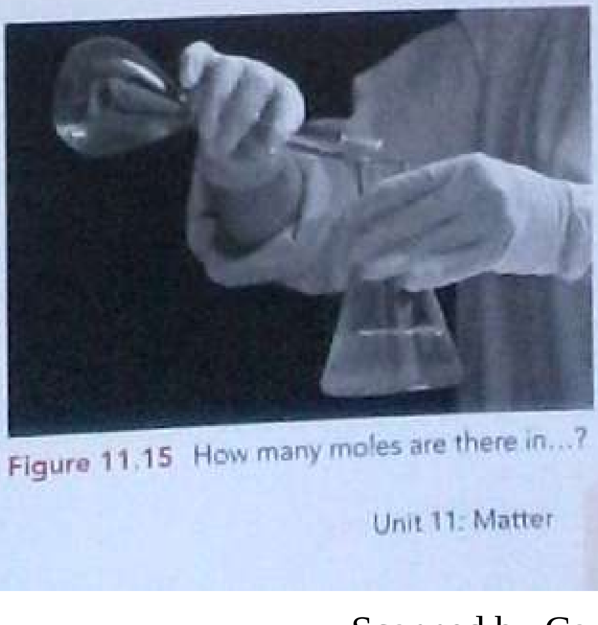


Figure 11.15 How many moles are there in...?

Exercise 11.12

1. What mass of each substance is needed to make a solution of concentration 1 mol/ℓ?
   a) sodium hydroxide (NaOH)
   b) potassium chloride (KCl)
   c) sodium carbonate (Na_2CO_3)
   d) copper sulphate ($CuSO_4$)
   e) lead nitrate ($Pb(NO_3)_2$)
2. Calculate the concentration of a solution that contains each of the following:
   a) 0.01 moles in 200 mℓ
   b) 0.5 moles in 2 ℓ
   c) 0.2 moles in 500 mℓ
   d) 1.5 moles in 1 ℓ
   e) 2.0 moles in 3 ℓ.
3. Determine the number of moles of substance present in the following:
   a) 50 mℓ of 0.01 mol/ℓ hydrochloric acid
   b) 20 mℓ of 2 mol/ℓ sodium carbonate.
4. What mass is needed to make each solution?
   a) 500 cm^3 of 0.1 mol/ℓ sodium chloride
   b) 5 cm^3 of 0.2 mol/ℓ potassium hydroxide
   c) 250 cm^3 of 1.5 mol/ℓ calcium chloride

Summary

- All atoms are made up of protons, electrons and neutrons.
- Neutrons have a relative charge of 0 and a relative mass of 1. Protons have a relative charge of +1 and a relative mass of 1. Electrons have a relative charge of –1 and a relative mass of $\frac{1}{1\,840}$.
- Every type of atom can be identified by the number of protons in its nucleus.
- The mass number of an element is the sum of the number of protons and the neutrons in an atom of that element.
- The atomic number of an element is the number of protons in an atom of that element.
- Isotopes are atoms of the same type but with different numbers of neutrons. This means that they have different mass numbers.
- The relative atomic mass of any atom is $\frac{1}{12}$ of the mass of a carbon-12 atom multiplied by the mass of that atom.
- The electrons in an atom are arranged in different energy shells. Each energy shell can only hold a certain number of electrons.
- The reactivity of elements is linked to their electron structures.
- A compound is a substance that contains two or more different elements that are chemically joined.
- Noble gases are nonreactive because their outermost shells are full.
- Atoms that form cations and anions can join to form ionic compounds.
- Strong electrostatic forces hold ions together.
- Compounds that are formed by shared electrons are called covalent compounds.
- Ionic compounds have higher melting and boiling points than covalent compounds.
- Positively charged ions are called cations and negatively charged ions are called anions.
- Compounds have a net charge of 0.
- Chemists use the relative atomic mass scale to compare the masses of atoms.
- The relative atomic masses of all atoms are obtained by comparison with the mass of carbon-12 atoms.
- The relative atomic mass of any element contains 6.02×10^{23} particles (Avogadro's number).
- The Avogadro constant is equivalent to one mole of a substance.

- A mole is the amount of substance that contains the same number of particles as there are atoms in 12 g of carbon-12.
- The relative atomic mass of a substance (in grams) contains one mole of the substance.
- Number of moles = $\frac{\text{mass}}{\text{molar mass}}$
- An empirical formula is the simplest ratio of the atoms of the different elements in a given compound.
- The number of moles of solute dissolved in one litre of liquid is the concentration.
- Concentration = $\frac{\text{number of moles}}{\text{volume in dm}^3}$

Glossary

anion – a negative ion

atomic number – the number of protons in an atom's nucleus (also called the proton number)

Avogadro's number – the number of particles in one mole of substance (N_A = 6.023 × 1023)

bond – as a verb it means to join chemically

cation – a positive ion

covalent bond – a type of chemical bond in which atoms share electrons between them

electronic configuration – the arrangement of electrons in energy shells around the nucleus

electron shell – the space in which electrons orbit the nucleus of an atom

electrostatic force – an attraction or repulsion between two particles, based on their electric charges

empirical formula – the simplest formula for a chemical compound, showing the simplest ratio in which the atoms combine

formula mass – the mass that one mole of a substance weighs (also molar mass)

group – the vertical columns of the Periodic table, containing elements with similar chemical properties

inert – nonreactive

ionic bond – a type of chemical bond where atoms either donate or receive electrons

ionic compound – a compound that has formed due to ionic bonding

isotopes – atoms of the same element with different numbers of neutrons

mass number – the number of protons and neutrons found in an atom's nucleus (also called the nucleon number)

metalloids – elements that have some metallic and some non-metallic properties

molar mass – the mass that one mole of a substance weighs (also formula mass)

mole – a measure of an amount of substance

molecular compound – a compound where atoms share electrons through covalent bonds

net ionic equation – a reaction equation showing only the ions that undergo a change during the reaction

noble gases – the inert (nonreactive) gases that make up Group 18 of the Periodic table

nucleon – a subatomic particle found in the nucleus of an atom (either a proton or a neutron)

nuclide notation – a short-hand way of writing information about the nucleus of an atom through the use of symbols and numbers

period – a horizontal row on the Periodic table

relative atomic mass – the mass of an atom as compared to $\frac{1}{12}$ the mass of a carbon-12 atom

relative molecular mass – the relative atomic masses for compounds and molecules (also relative formula mass)

relative mass – of a subatomic particle: the mass of that particle in relation to the mass of a proton

valence electrons – the electrons in the outermost shell of an atom; the electrons involved in bonding

valency – the number of electrons an atom must *lose* or *gain* to obtain a noble gas configuration

Revision questions

1. Phosphorus has an atomic number of 15. Which answer shows how the electrons of a phosphorus atom are arranged in the energy shells?
   - A. 2,5,8
   - B. 2,6,8,5
   - C. 2,8,5
   - D. 5,5,5 (1)
2. Isotopes are atoms of the same element. In which number do they differ?
   - A. protons and electrons
   - B. neutrons and protons
   - C. protons only
   - D. neutrons only (1)
3. What do the elements potassium, sulphur and chlorine have in common? Choose the correct answer.
   - A. They form negative ions.
   - B. They are non-metals.
   - C. Their ions have the electron structure of argon.
   - D. They form positive ions. (1)
4. Element X has the electron structure 2,8,7. What is the formula of its ion? Choose the correct answer.
   - A. X^-
   - B. X^{2+}
   - C. X^{2-}
   - D. X^+ (1)
5. Which compound in this table is most likely to be an ionic compound?

Compound	Melting point (°C)	Boiling point (°C)	Property
A	801	1 517	Conducts electricity in solution, but not when solid.
B	78	132	Does not conduct electricity in solution or when solid.
C	900	2 000	Conducts electricity when in solid state or molten.
D	39	357	Dissolves in an organic solvent.

(1)

6. What is the neutron number of an atom with a mass number of 31 and an atomic number of 14? (1)
7. Copy and complete the table below.

Element	Protons	Electrons	Neutrons
^{12}X			6
^{14}X	6		

(4)

8. Draw dot-and-cross diagrams to represent the following compounds.
   - a) hydrogen sulphide (H_2S)
   - b) calcium chloride ($CaCl_2$)
   - c) ammonia (NH_3) (9)
9. Calculate the mass of the following:
   - a) 0.5 moles of sulphur dioxide
   - b) 0.01 moles of sodium
   - c) 0.05 of oxygen atoms
   - d) 1.5 moles of sulphuric acid
   - e) 0.1 moles of sodium chloride (15)

10. Copy and complete the table below.

Atom	Notation	Atomic number	Mass number	Protons	Neutrons
chlorine		17			18
	[illegible]Ca				
				1	0
boron			11	5	
		16	33		

(19)

11. How many particles are there in the following?
    a) 4 g of magnesium
    b) 18 g of water
    c) 0.44 g of carbon dioxide
    d) 0.1 moles of hydrochloric acid (12)

12. 15.3 g of aluminium is combined with 13.6 g of oxygen to form aluminium oxide.
    a) Express the given masses in moles. (2)
    b) What is the empirical formula of the product? (5)

13. How many moles are there in the following?
    a) 32 g of sulphur
    b) 0.6 g of carbon
    c) 4.4 g of carbon dioxide
    d) 1.8 g of water (12)

14. The following results were obtained in an experiment to find the formula of magnesium oxide:
    - mass of crucible: 12.5 g
    - mass of crucible and magnesium: 14.9 g
    - mass of crucible and magnesium oxide: 16.5 g.

    a) What mass of magnesium was used in this experiment? (1)
    b) How many moles of magnesium atoms are there in the magnesium oxide? (2)
    c) What mass of oxygen combined with the magnesium? (2)
    d) How many moles of oxygen atoms were needed for the reaction? (2)
    e) What is the molecular formula of magnesium oxide? (4)

TOTAL: 95

Unit 12 Acids and bases

Objectives

- Identify the regions of acidity, neutrality and alkalinity of a substance on the pH scale and when using universal indicator solution.
- Describe the reactions of acids with alkalis (or bases) and metals.
- Write word and chemical equations for reactions.

Introduction

In Form 1, we described acids as substances that have a sour taste and alkalis as substances that feel slippery when you touch them. Of course, these descriptions can only apply to non-toxic household substances – not to the sorts of acids and alkalis that we work with in the laboratory.

In fact, as we will see in this unit, acids and alkalis (or bases) are defined in chemical terms according to how they behave when they are dissolved in water.

Acids, bases and alkalis

In 1887, scientist Svante Arrhenius suggested a way to define acids and bases. When you put these compounds into water, they break down (dissociate) and they either release a hydrogen ion (H^+) or a hydroxide ion (OH^-). When a hydrogen ion is released, the solution becomes acidic. When a hydroxide ion is released, the solution becomes alkaline. These two ions determine whether a compound is an acid or a base. If a base can dissolve in water, it is called an alkali.

Acids and bases can be strong or weak. Strong acids and strong bases are very dangerous. They are corrosive, that is, they can eat away metals and other materials. Strong acids and bases can cause serious burns. The acids and alkalis students use in the laboratory are usually diluted with water.

The pH scale

The pH of a substance that can dissolve in water is a measure of how acidic or basic that substance is. The pH scale ranges from 0 to 14. Acids have pH values below 7 while alkalis have pH values above 7. Neutral substances are neither acidic nor basic; they have a pH value of 7.

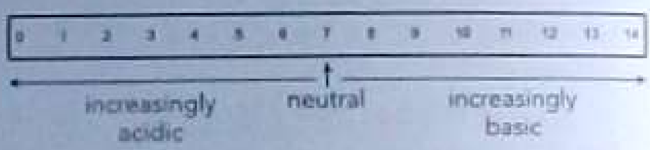


Figure 12.1 The pH scale

Strong acids have the lowest pH numbers. Although it is theoretically possible for an acid to have a pH of 0, we seldom work with pH values below 1. Weak acids have pH values just below 7. Strong alkalis have the highest pH numbers. We do not work with pH values above 14. Weak alkalis have pH values just above 7. The pH value represents the concentration of H^+ ions. The table below shows examples of strong and weak acids and bases.

Substance	Description	pH
hydrochloric acid (stomach acid)	strong acid	1
milk	weak acid	6
ammonia	weak base	11
sodium hydroxide (drain cleaner)	strong base	14

As the concentration of the H^+ ion increases, the pH decreases, and as the strength of the OH^- ion increases, the pH increases.

You can view the name, **pH**, as an abbreviation for "the power of the concentration of H^+ ions".

What about water?

An acid is a substance that dissociates to produce H^+ ions and a base is a substance that dissociates to produce OH^- ions. However, water dissociates to form both H^+ and OH^- ions in a **reversible reaction** (the reaction can go forwards and backwards). This means that water can be a base or an acid depending on how you look at it! So, we now say that an acid is any substance that increases the concentration of H^+ ions when it dissolves in water and a base is any substance that increases the concentration of OH^- ions.

Using these definitions, it is easy to test whether a compound is an acid or an alkali. You can simply dissolve the substance in water and test the solution to see whether the H^+ or OH^- ion concentration has increased.

Indicators

We use **indicators** to measure the pH of a solution. An indicator is a substance that changes colour according to the acidity or alkalinity of the solution it is in. Litmus paper is an example of an indicator. It becomes red in acidic solutions and blue in alkaline solutions. One of the most important indicators is universal indicator. It is a mixture of dyes that change colour gradually over a range of pH values.

The table below shows a few indicators and their colour changes.

Indicator	Colour in acid	Colour in alkali
litmus	red	blue
methyl orange	red	yellow
phenolphthalein	colourless	red
universal	red	purple

Strong and weak acids

When some acids dissolve in water, they give away all the hydrogen ions they possess. Examples of this type of acid include hydrochloric, nitric and sulphuric acids. These acids dissociate fully in water. Acids that dissociate completely into ions in water are called *strong acids*. The term strong refers to the extent of dissociation and not to the concentration. While adding water to an acid dilutes it, this does not make it a weaker acid.

Ethanoic acid is a *weak acid*. When it dissolves in water, it does not give away all its hydrogen ions. The acid only partially dissociates.

Strong and weak alkalis

Some alkalis dissolve in water to give away all their hydroxyl ions. Examples of this type of alkali include sodium hydroxide, potassium hydroxide and calcium hydroxide. Alkalis that fully dissociate in water to give hydroxyl ions are called *strong alkalis*.

Ammonia solution is an example of a *weak alkali*. It only partially dissociates in water, which means that it does not give away all its hydroxyl ions.

Experiment 12.1

Aim: To investigate the effects of acids and bases on universal indicator

Materials: 7 beakers, universal indicator, hydrochloric acid, sodium hydroxide solution, distilled water, an ammonia-based household detergent, toothpaste, lemon juice, coffee

Procedure

1. Label each beaker according to the seven substances we will test (hydrochloric acid, sodium hydroxide solution, distilled water, household detergent, toothpaste, lemon juice and coffee).
2. Pour or place a small amount of each liquid into its matching beaker.

3. Place a few drops of universal indicator in the first beaker. Observe and note any changes that occur.
4. Repeat Step 3 for each of the beakers.

Results

Complete the table below using the pH key that comes with the universal indicator.

Substance	Colour of universal indicator	pH value	Acid or alkali?
hydrochloric acid (HCl)			
sodium hydroxide (NaOH)			
distilled water			
ammonia-based detergent			
toothpaste			
lemon juice			
coffee			

Questions

1. How many acids did you identify in the group of seven substances?
2. How many substances had a pH-value in the range of 6 to 8?
3. Draw a simple pH scale and place the names of each of the substances tested at their correct pH-reading.

Reactions involving acids

In this section, we will investigate a few specific types of reactions where acids react with metals, bases and carbonates. You will notice certain patterns for the reaction of acids with members of these groups.

Reactions of acids with metals

Only some metals react with ordinary dilute acids. Very reactive metals, like potassium and sodium, react explosively with dilute acids. However, other metals such as gold and silver, do not react with dilute acids at all.

In Form 4, you will learn about the reactivity series, which informs us which metals are highly reactive and which are not.

Metals react with acids to produce a salt and hydrogen. The general word equation for such a reaction is:

metal + acid → salt + hydrogen gas

Experiment 12.2

Aim: To investigate the reactions of acids with metals

Materials: a rack of test tubes, dilute hydrochloric acid, dilute sulphuric acid, dilute nitric acid, ethanoic acid, magnesium ribbon, metal turnings (zinc, iron and copper)

Procedure

1. Fill the five test tubes – each to one quarter full with one of the acids.
2. Drop a piece of magnesium ribbon into each test tube. Carefully observe what happens.
3. Repeat the experiment a number of times, each time using a fresh set of acids and a different metal, until you have tested all the metals.

4. Record all your results in a table like the one below.

Metal	Reaction with hydrochloric acid (HCl)	Reaction with sulphuric acid (H_2SO_4)	Reaction with nitric acid (HNO_3)	Reaction with ethanoic acid ($C_2H_4O_2$)
magnesium				
zinc				
iron				
copper				

Results

Not all metals evolve hydrogen when they react with acids. You should have noticed that copper behaved differently compared to the other metals. It only reacted with concentrated nitric acid and evolved a brown gas (nitrogen dioxide). This is a typical characteristic of metals that are low in the reactivity series.

Questions

1. Based on your results, which metal was:
   a) the most reactive?
   b) the least reactive?
2. Which acid was the least effective in the experiment? Give a reason for your answer.
3. What test could we perform to confirm that hydrogen gas was released in each of the successful reactions?
4. Write a word equation for the reaction of magnesium with hydrochloric acid.

Metals that are very reactive, such as potassium, sodium and calcium, react violently with acids.

The salt produced when an acid reacts with a metal depends on the acid that is used in the reaction:

- Sulphuric acid reacts with metals to form sulphate salts.
- Hydrochloric acid reacts with metals to form chloride salts.
- Nitric acid reacts with metals to form nitrate salts.
- Ethanoic acid reacts with metals to form ethanoate salts.

Reactions of acids with bases

Metal oxides and hydroxides are bases and so they have the ability to make an acid less acidic. We call this type of reaction a **neutralisation reaction**, as both the acid and the alkali are effectively neutralised when they come into contact with each other. As we would expect, the pH of the products is 7, that is, neutral.

All metals oxides react with acids in the same way:

metal oxide + acid → salt + water

For example:

$MgO + 2HCl \rightarrow MgCl_2 + H_2O$

$CaO + H_2SO_4 \rightarrow CaSO_4 + H_2O$

$Na_2O + 2HNO_3 \rightarrow 2NaNO_3 + H_2O$

Acids and metal hydroxides

Metal hydroxides react similarly to acids:

metal hydroxide + acid → salt + water

For example:

$NaOH + HCl \rightarrow NaCl + H_2O$

$2KOH + H_2SO_4 \rightarrow K_2SO_4 + 2H_2O$

$Mg(OH)_2 + 2HNO_3 \rightarrow Mg(NO_3)_2 + 2H_2O$

Experiment 12.3

Aim: To investigate the reactions of acids with metal hydroxides

Materials: sodium hydroxide solution, dilute hydrochloric acid, a dropper, universal indicator, a test tube or small beaker, a teaspoon or measuring cylinder

Procedure

1. Place about 10 mℓ (two teaspoons) of sodium hydroxide solution in the test tube or beaker.
2. Add a drop of universal indicator. Use the colour of the indicator to determine the pH of the sodium hydroxide.
3. Use the dropper to add hydrochloric acid to the sodium hydroxide. Swirl the beaker or test tube after every few drops.
4. When the indicator turns light blue, add one drop of acid at a time. Stop when the indicator turns green.

Results

The hydrochloric acid reacts with the sodium hydroxide solution to produce a specific set of products.

Questions

1. Explain the meaning of the green colour of the indicator.
2. Write a word equation and balanced symbol equation for the reaction in the test tube

Exercise 12.1

Write a word equation and a balanced chemical equation for each reaction.

1. sodium hydroxide and nitric acid
2. calcium hydroxide ($Ca(OH)_2$) and hydrochloric acid
3. magnesium hydroxide ($Mg(OH)_2$) and sulphuric acid
4. potassium hydroxide and hydrochloric acid
5. aluminium hydroxide ($Al(OH)_3$) and hydrochloric acid

Reactions of acids with carbonates

Carbonates are also bases. Carbonates react with acids in the following way:

carbonate + acid → salt + carbon dioxide + water

For example,

$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$

$MgCO_3 + H_2SO_4 \rightarrow MgSO_4 + H_2O + CO_2$

$Na_2CO_3 + 2HNO_3 \rightarrow 2NaNO_3 + H_2O + CO_2$

Experiment 12.4

Aim: To investigate the reactions of acids with carbonates

Materials: calcium carbonate, hydrochloric acid, sulphuric acid, nitric acid, test tubes, a spatula

Procedure

1. Place about 2 mℓ of dilute hydrochloric acid in a test tube.
2. Add a spatula of calcium carbonate. Record your observations and test any gas evolved.

3. Repeat the experiment two more times – once using nitric acid and once using sulphuric acid. Record all your observations in a table like the one below.

Results

Reaction of calcium carbonate and ...	Observations	Gas evolved (if any)
hydrochloric acid		
sulphuric acid		
nitric acid		

Questions

Write down the equation for the reaction of calcium carbonate with each acid.

1. hydrochloric acid
2. sulphuric acid
3. nitric acid

Figure 12.2 Investigating the reactions of acids with carbonates

Summary

- Acids react readily with highly reactive metals, carbonates and metal oxides.
- Acids are neutralised by metal oxides, hydroxides and bases.
- Carbonates react with acids to give a salt, carbon dioxide and water
- Metal oxides react with acids to give a salt and water
- Metal hydroxides also react with acids to give a salt and water.
- Acids have pH values below 7.
- Bases have a pH of greater than 7.
- The reaction between an acid and a base is called a neutralisation reaction.
- The term base is used to describe all the compounds that can neutralise acids.
- Examples of bases include metal oxides, metal carbonates, metal hydroxides and ammonia solution.

Glossary

indicator – a substance that changes colour according to the acidity or alkalinity of the solution it is in

neutralisation reaction – a reaction in which an acid and an alkali cancel out each other's acidity and alkalinity when they come into contact with each other; a reaction where only a salt and water form

reversible reaction – a reaction that can proceed forwards and backwards; a reaction that goes in either direction

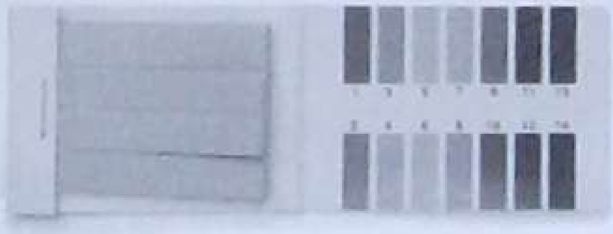


Figure 12.3 You can measure the pH of a substance with indicator paper

Revision questions

1. Which of the following applies to a solution of sulphuric acid?
   - **A** It is a poor conductor of electricity.
   - **B** It has a pH below 7.
   - **C** It will react with copper to produce hydrogen gas.
   - **D** It does not react with zinc carbonate. (1)
2. Which of the following reactions will not take place?
   - **A** calcium oxide + dilute nitric acid
   - **B** potassium hydroxide + dilute sulphuric acid
   - **C** copper + dilute hydrochloric acid
   - **D** magnesium + dilute hydrochloric acid (1)
3. A water solution of a certain acid has a pH of 5. Which of the following is the most reasonable conclusion about the solution?
   - **A** The acid is too dilute.
   - **B** The acid is only slightly soluble in water.
   - **C** The acid is not a strong acid.
   - **D** The acid reacts with water to produce a high concentration of H^+ ions.
   - **E** The acid is a poor electrolyte. (1)
4. When a sodium hydroxide solution is added to dilute hydrochloric acid in a beaker, which of the following does not happen?
   - **A** The pH of the solution increases.
   - **B** The OH^- ion concentration is neutralised.
   - **C** The H^+ ions neutralise some of the OH^- ions.
   - **D** The volume of water increases.
   - **E** The reaction $Na^+ + Cl^- \rightarrow NaCl$ takes place. (1)
5. Write down the equation for each reaction.
   - **a)** hydrochloric acid and sodium carbonate
   - **b)** sulphuric acid and magnesium oxide (4)
6. What do you observe when a small amount of marble chips ($CaCO_3$) is dropped into a test tube that contains dilute hydrochloric acid? (1)
7. The components of two washing powders, X and Y, are listed in the table below. Dilute hydrochloric acid was added to each powder.

Component	Powder X (%)	Powder Y (%)
sodium sulphate	0	35
sodium carbonate	30	0
sodium silicate	20	26
sodium soap	12	14
detergent	18	13

   - **a)** Which powder fizzed? (1)
   - **b)** Name the gas evolved. (1)
   - **c)** Draw a labelled diagram of how you would test for this gas. (4)
   - **d)** What would you observe in this test? (2)
8. What is an indicator? (1)
9. Name two common indicators and give their colours in acid solutions. (2)

TOTAL: 20

Unit 13 Industrial processes

Objectives

- Outline the production of nitrogen and oxygen.
- Define electrolysis.
- Label the general components of an electrolytic cell.
- List the properties of the electrodes and the electrolyte.
- Describe anode and cathode reactions for electrolysis of molten lead bromide.
- List observations for the electrolysis of molten lead bromide.
- Describe the process of electrolysis of water.
- State the products formed during the electrolysis of water.
- List the uses of oxygen and hydrogen.
- Identify the cathode, anode and electrolyte.
- Explain the cathode process.
- List reasons for electroplating materials.

Introduction

Large volumes of gases are needed in industries. For example, oxygen is needed in the steel industry and hydrogen and nitrogen are needed in the Haber process to produce ammonia.

Since air contains large amounts of nitrogen and oxygen, these gases can be separated from the air. However, oxygen (and hydrogen) can be isolated using other techniques, such as electrolysis. In this unit, we will investigate the production of nitrogen and oxygen, but will focus on the importance of electrolysis in industrial applications.

The fractional distillation of liquefied air

Air contains a mixture of gases, such as nitrogen, oxygen, argon, carbon dioxide and water vapour. Oxygen and nitrogen can be separated from the mixture of gases in air by a process called the fractional distillation of liquefied air. Figure 13.1 shows a flow diagram of this process which is relatively cheap and easy.

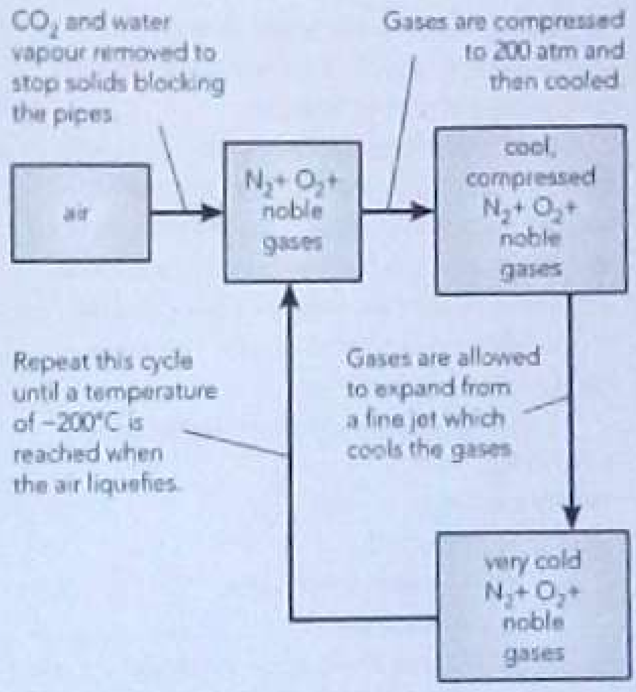


Figure 13.1 The liquefaction of air

1. Air is pumped into the plant and it passes through a filter to remove dust particles.
2. The temperature is reduced to −56 °C. Carbon dioxide and water vapour solidify and are removed.

3. The air is then forced into a smaller volume so that its pressure increases. It first becomes hot, but is suddenly cooled down.
4. The cooled air is forced to expand and this cools the air further. The process is repeated several times until the gas mixture turns into a liquid.
5. The liquid air is then pumped into a fractionating column where it is warmed slightly. The gases boil off one by one and are collected in different tanks. Nitrogen boils off at –196 °C and is followed by oxygen that boils off at –183 °C.

In this way, these two industrially important gases are isolated for particular uses: Nitrogen is used in the production of ammonia and nitric acid, while oxygen is used in steelmaking, welding and for medical treatment.

Project

In groups, research the topic of fractional distillation of liquefied air using the Internet and write a report to hand in.

For both nitrogen and oxygen, you will need to detail how the gas is separated from air industrially. You must also find out how the gas is used once it has been isolated from air. Find at least four uses for each gas, and write a short description of how the gas is used in those applications.

Marks will be awarded according to the following:

Written report

1.	Structure	(3)
2.	Content/conclusion	(10)
3.	Neatness	(2)
4.	List of resources consulted	(5)
		TOTAL: 20

Electrolysis

In Form 2, we learnt about chemical reactions in which heat was an important agent in creating change. Another very important form of energy in causing chemical changes is electrical energy. For example, we can use electricity to decompose molten sodium chloride into its component elements:

$$2NaCl(l) \rightarrow 2Na(l) + Cl_2(g)$$

In this section, we will study the effect of passing electricity through different substances and find out what chemical changes take place during this process.

What is electrolysis?

Electrolysis means to break down or decompose through the use of an electric current. Electrolysis is an electrochemical reaction in which electrical energy is converted to chemical energy. For example, when an electric current is passed through a copper(II) chloride solution, a reaction occurs that produces solid copper and chlorine gas. Electrolytic reactions are redox reactions (about which we will learn more in the next unit).

Electrolysis takes place in **electrolytic cells**. Figure 13.2 shows a simple electrolytic cell. The diagram shows that it is made up of a DC voltage supply (the external circuit), two **electrodes** and an **electrolyte**. The components that make contact with the electrolyte are called electrodes. Inert electrodes are electrodes that do not take part in the electrolysis process. All the chemical changes happen at the two electrodes. Oxidation takes place at the **anode** (positive electrode) and reduction takes place at the **cathode** (negative electrode). The electrolyte is a substance that contains ions in solution and therefore conducts electricity.

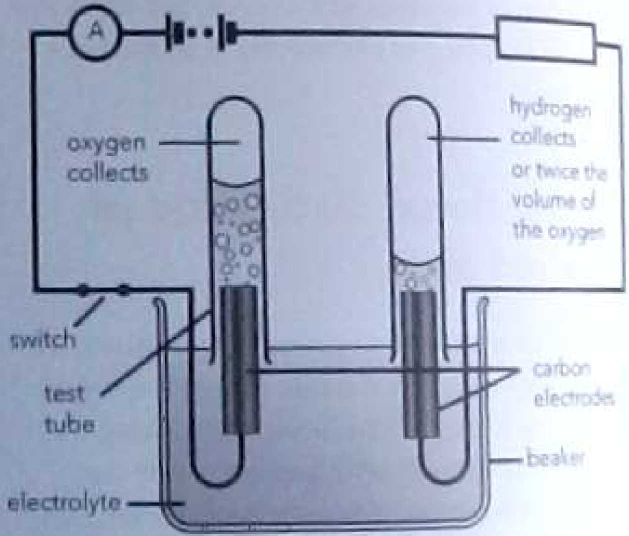


Figure 13.2 A simple electrolytic cell used to break down water

Experiment 13.1

Aim: To set up and investigate an electrolysis experiment

Materials: a large beaker or basin, two 5-mm carbon electrodes, a retort stand and clamp, a DC power supply of two 1.5-V batteries, connecting wires, crocodiles clips, 0.5 mol/dm^3 copper(II) sulphate solution, emery nail file

Procedure

1. Clean the electrodes with the emery nail file.
2. Set up a circuit as shown in Figure 13.3. Use the retort stand and clamps to secure the electrodes in a vertical position.
3. As the current flows through the circuit, note any visible changes to or near the electrodes.

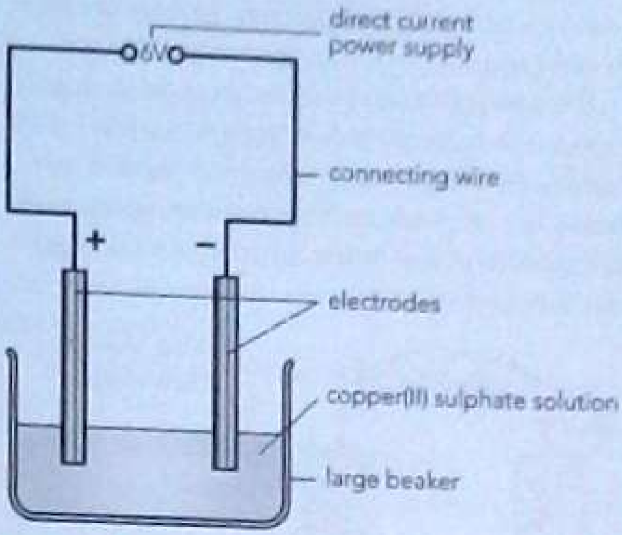


Figure 13.3 The electrolysis of copper(II) sulphate solution (include a switch for all such circuits)

Results

You should notice that bubbles form at one of the electrodes and that an even, shiny brown and hard deposit builds up on the other electrode.

Questions

1. Which electrode is the anode?
2. The bubbles that form at one electrode are oxygen gas bubbles. Where did the oxygen come from: the air or the electrolyte?
3. Name the metal that forms on the other electrode.
4. Complete the sentence: _______ forms at the anode and _______ forms at the cathode during the electrolysis of copper(II) sulphate solution.
5. Draw a simplified sketch of the experiment set-up. Label all the key components and indicate which substances are formed, and where.

The electrolysis of molten compounds

Figure 13.4 shows the electrolysis of molten lead bromide. When the lead bromide is solid, nothing happens. However, as soon as it melts:

- the bulb lights up, showing that electrons are flowing through it
- bubbles are produced around the anode as bromine is given off
- nothing seems to be happening around the cathode but metallic lead is found underneath the end
- when the heat is taken away and the lead bromide solidifies again, everything stops: the bulb goes out and no more bubbles are produced.

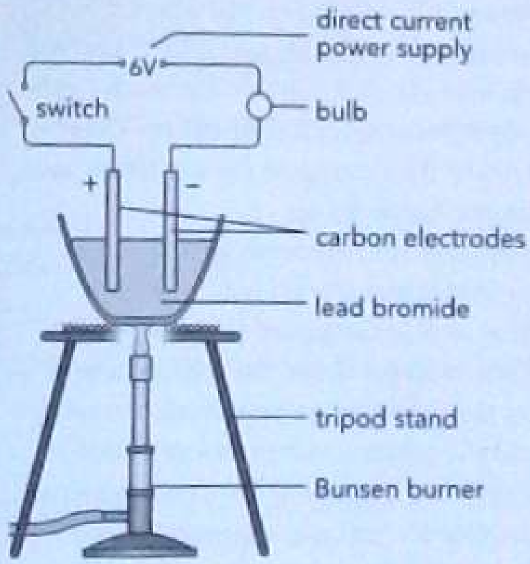


Figure 13.4 The electrolysis of molten lead bromide

Explaining what happens

Lead bromide is an ionic compound. In its solid form, its ions are not free to move. Therefore, solid lead bromide does not conduct electricity. However, as soon as the solid melts, the ions become free to move around and this movement makes it possible for the electrons to flow in the external circuit.

The power source acts as an electron 'pump'. As soon as it is connected, it 'pumps' mobile electrons away from the electrode on the left towards the electrode on the right (see Figure 13.5). The excess electrons in the electrode on the right make it negatively charged.

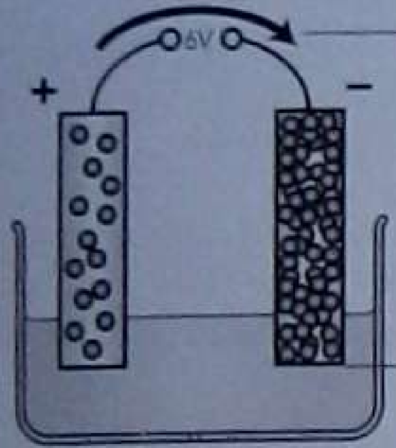


Figure 13.5 The direction of electron flow in an electrolytic cell

The electrode on the left is positively charged, because it is short of electrons.

However, when the lead bromide melts and the ions become free to move, the positive lead ions are attracted to the cathode. When they get there, each lead ion picks up two electrons from the cathode to form neutral lead atoms. These electrons fall to the bottom of the container as liquid lead (see Figure 13.6).

The lead ions gain electrons and are thus reduced to lead atoms: $Pb^{2+}(l) + 2e^- \rightarrow Pb(s)$

Bromide ions are attracted to the positive anode. When they get there, the extra electron that makes the bromide ion negatively charged, moves onto the anode because this electrode is short of electrons. The loss of the extra electron turns each bromide ion into a bromine atom. These join together in pairs to form bromine molecules (see Figure 13.7). The bromine ions lose

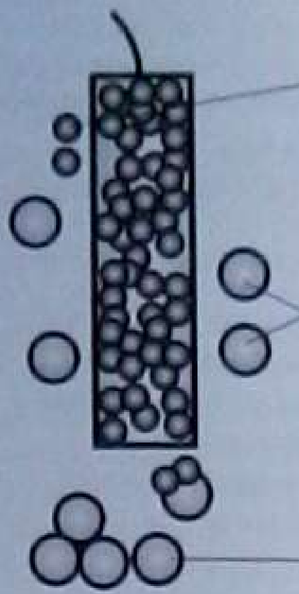


Figure 13.6 The process at the cathode

electrons and so are oxidised to bromine atoms that then combine to form bromine molecules:

$$2Br^-(l) \rightarrow Br_2(g) + 2e^-$$

The new electrons on the anode are pumped away by the power source to help fill the spaces that are created in the cathode. The flow of current in the external circuit is maintained by the flow of these electrons while the flow of lead ions and bromine ions complete the circuit in the molten lead bromide.

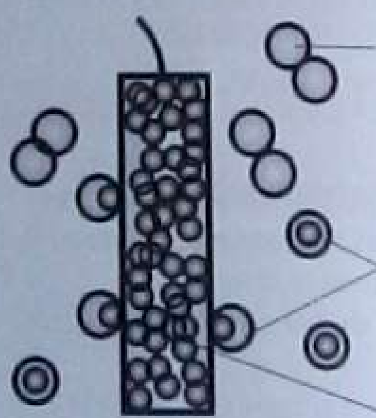


Figure 13.7 The process at the anode

In any example of electrolysis, reduction occurs at the cathode and oxidation occurs at the anode. In each case, the positive ions (cations) are attracted to the negative cathode where they discharge by gaining electrons. The negative ions (anions) move to the anode where they discharge by giving electrons to the electrode.

The electrolysis of aqueous solutions

When a salt is dissolved in water, an **aqueous solution** of the salt is formed. In aqueous solutions we find H^+, OH^- plus the cation and anion from the compound from which the solution is derived. For example, in Experiment 13.1 we experimented with the electrolysis of copper(II) sulphate solution. This solution contains the ions H^+, OH^-, Cu^{2+} and SO_4^{2-}.

In the electrolysis of $CuSO_4$, a thick layer of copper is deposited on the cathode. This occurs because the positive ions (Cu^{2+} and H^+) migrate to the negative cathode. The copper ions (rather than the H^+ ions) are preferentially discharged as copper at the cathode. The red-brown colour of copper is seen at the cathode. The hydroxyl ions are preferentially discharged at the anode, where oxygen and water are formed.

At the anode: $4OH^- \rightarrow 2H_2O + O_2 + 4e^-$

At the cathode: $Cu^{2+} + 2e^- \rightarrow Cu$

The hydrogen and sulphate ions remain in solution. The concentration of these ions makes the remaining solution more acidic.

The hydrogen and sulphate ions make the solution more acidic if carbon electrodes are used. If copper electrodes are used, the red-brown copper is still discharged at the cathode. The cathode increases in size as it gains more copper. However, no gas is evolved at the anode. The anode becomes thinner and thinner as it releases copper ions into the electrolyte.

In the electrolysis of dilute sodium chloride, the hydroxyl ions (OH^-) rather than the chloride ions are preferentially discharged at the anode. The H^+ ions are preferentially discharged, rather than the Na^+ ions, at the cathode.

Experiment 13.2

Aim: To investigate the electrolysis of water in the presence of dilute sulphuric acid

Materials: a large beaker or basin, two 5-mm carbon electrodes, a retort stand and clamps, a 12-V DC power supply, connecting wires, crocodiles clips, two large boiling tubes, concentrated sulphuric acid, dropper, water

Procedure

1. Fill the beaker with water and add a few drops of concentrated sulphuric acid using the dropper.
2. Set up the apparatus as shown in Figure 13.8.
3. Electrolyse the acid by allowing the current to flow around the circuit.
4. Compare the volume of gases collected in each tube.
5. Test the gases collected to confirm your guesses as to what they are.

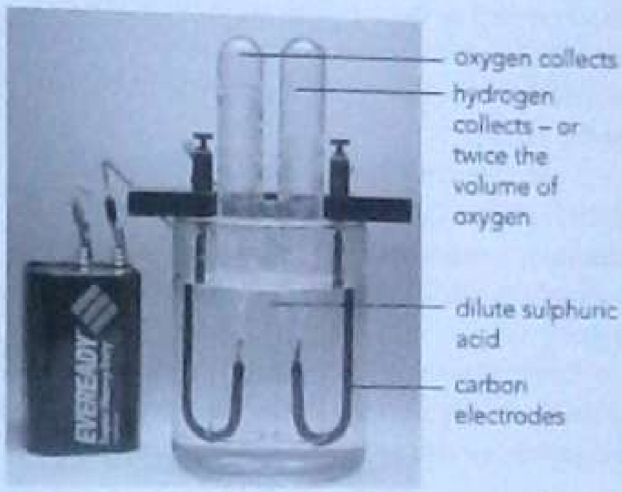


Figure 13.8 Electrolysis of dilute sulphuric acid

Results

Water has decomposed into hydrogen and oxygen. Bubbles of gas were seen at the electrodes. This gas is hydrogen. In the other test tube is oxygen.

Questions

1. Which ions are attracted to the anode? Which ions are preferentially discharged at this electrode?
2. Which ions are attracted to the cathode? Which ions are preferentially discharged at this electrode?
3. Write down equations to summarise the processes that occur at the anode and the cathode.

In this experiment, only H^+ ions migrate to the cathode. They are discharged as hydrogen gas:

$2H^+ + 2e^- \rightarrow H_2$

Sulphate and hydroxyl ions migrate to the anode, where the hydroxyl ions are preferentially discharged and oxygen gas is released:

$4OH^- \rightarrow 2H_2O + O_2 + 4e^-$

Twice as much hydrogen is produced as oxygen because for every four electrons that flow around the circuit, there will be one molecule of oxygen. However, four electrons would produce two molecules of hydrogen. Water alone does not conduct electricity. But adding a small amount of sulphuric acid makes it a good conductor of electricity.

Uses of hydrogen and oxygen

The electrolysis of water is one of the main methods used in industry to obtain oxygen and hydrogen in large quantities.

In Zimbabwe, an electrolysis plant is situated in Kwekwe at the Sable Chemical Industry. The water needed as the raw material is drawn from the Sebakwe River. There is a large power station at Munyathi, which provides the electricity needed by the plant.

One important reason why the electrolysis plant is situated in Kwekwe is because the products, oxygen and hydrogen, are used as raw materials at ZISCO and Sable Chemical Industries, respectively.

Hydrogen is used in welding, the manufacture of fertilisers and also the manufacture of margarine, as well as for the Haber process.

Generally, oxygen gas is used in steelmaking (it is needed in the process of producing steel from pig iron) and it has medical uses.

Electroplating

Electroplating is a process during which one metal is covered with another metal. In this process, one metal can be covered with a layer of metal that is more decorative, expensive or more resistant to corrosion than the metal that is being covered. In the process of electroplating, the article to be plated is the cathode and a bar of the plating material is the anode.

Chromium, silver and gold can be used to electroplate items.

For example, to silver plate an object, the object is hung in a solution of silver nitrate and it becomes the cathode in an electrical circuit (see Figure 13.9). The anode is a piece of silver. At the cathode, silver ions are discharged when an electron is picked up and metallic silver is formed. The metallic silver plates the object. The anode becomes thinner as it 'dissolves' during the process. At the same time, silver covers the object.

At the anode: $Ag \rightarrow Ag^+ + e^-$

At the cathode: $Ag^+ + e^- \rightarrow Ag$

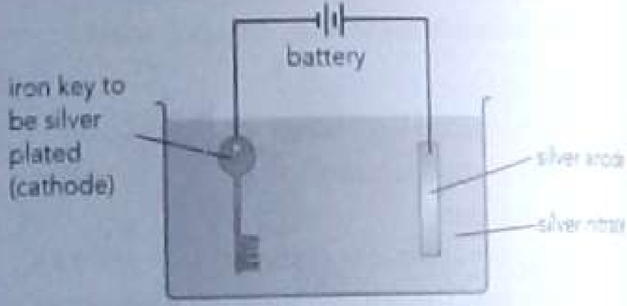


Figure 13.9 Electroplating with silver

The table below shows a few electroplating substances and their anode reactions.

Substance	Electrolyte	Anode reaction	Use
copper	copper(II) sulphate	$Cu \rightarrow Cu^{2+} + 2e^-$	decorative; prevents corrosion
chromium	chromic acid	$Cr \rightarrow Cr^{3+} + 3e^-$	prevents corrosion; shiny
gold	gold(III) sulphate	$Au \rightarrow Au^{3+} + 3e^-$	decorative; prevents corrosion
nickel	nickel(II) sulphate	$Ni \rightarrow Ni^{2+} + 2e^-$	prevents corrosion
tin	tin(II) sulphate	$Sn \rightarrow Sn^{2+} + 2e^-$	food containers

Experiment 13.3

Aim: To electroplate an iron nail

Materials: an iron nail, soap and water, paper towel, a 1.5-V battery in a battery holder, 2 crocodile clips, a beaker, concentrated copper sulphate solution, a coil of copper wire

Procedure

1. Wash the iron nail with soap and water and dry it on the paper towel.
2. Clip the coil of copper wire in one side of a crocodile clip and attach the other side of the crocodile clip to the positive terminal of the battery.
3. Clip the iron nail in one side of the second crocodile clip, and attach the other side of the crocodile clip to the negative terminal of the battery.
4. Suspend both the coil of copper wire and the iron nail in the copper sulphate solution. The crocodile clips must not be in contact with the liquid.
5. Let the circuit run for 20 minutes or more, if needed, until you see a layer of copper on the iron nail.

Results

Depending on the materials used, the iron nail should have a reasonable coating of copper metal over its surface that was submerged in the copper sulphate solution. Note that if the copper sulphate solution is not concentrated enough, a black substance will form on the nail instead of a copper-coloured coating.

Questions

1. Which material (the coil of copper wire or the iron nail) acted as the anode in this experiment?
2. The results of the experiment depend on a number of factors. One of which is the concentration of the copper sulphate solution. Name two other factors that may influence the copper-plating experiment.

Activity 13.1

In Form 1 you learnt about the reasons for electroplating various metals. In groups, recall and discuss some of the reasons why we electroplate certain metals.

Summary

- All metals conduct electricity because they contain free electrons that pass electricity from one electron to another.
- Ionic compounds conduct electricity when they are molten or in aqueous solution. The conducting solution is called an electrolyte.
- The decomposition of ionic compounds into their constituent elements is called electrolysis.
- The positive electrode is called the anode and the negative electrode is called the cathode.
- The ease with which ions are reduced or oxidised at the electrodes depends on the position of the ions in the activity series.

- Inert electrodes do not react with the electrolytes during electrolysis. Active electrodes dissolve during electrolysis.
- Water and oxygen are both required for iron to rust.
- Materials are coated for protection and decoration.
- Electroplating is the process of coating one metal with another type of metal.
- Coating prevents oxygen and moisture from reaching a metal.

Glossary

anode – the positive electrode, where oxidation takes place during electrolysis

aqueous solution – a solution where the solvent is water

cathode – the negative electrode, where reduction takes place during electrolysis

electrode – conducting material used to pass electrical current to the electrolyte during electrolysis

electrolysis – breaking up chemical substances by means of electricity

electrolyte – a substance that contains ions in solution and therefore is able to conduct electricity

electrolytic cell – a type of electrochemical cell that undergoes a redox reaction when it is part of an electrical circuit

electroplating – a process during which one metal is covered with another metal using electricity

Revision questions

1. The liquid that is in contact with the electrodes during electrolysis is called:
   A. the anode B. the cathode
   C. the electrolyte D. the electrolytic cell. (1)
2. When an electric current is passed through a compound in solution, the compound is broken down. What name do we give to this process?
   A. electrostatics B. electrolysis
   C. melting D. decomposition (1)
3. Consider the electrolysis of copper(II) bromide.
   a) Draw and label a diagram of the electrolysis of copper(II) bromide. (6)
   b) Show the direction of current flow and the direction of electron flow on your diagram. (2)
   c) Write down the equations for the processes that occur at each electrode. (4)
   d) What would you observe at each electrode? (2)
4. Consider the electrolysis of water.
   a) With the help of a diagram, describe an experiment in which you could collect the products of this electrolysis. (5)
   b) Describe a test that could be used to identify the product that is collected at the anode. (2)
   c) Why are the products always collected in the ratio 1 : 2? (2)

TOTAL: 25

Unit 14 Oxidation and reduction

Objectives

- Define oxidation.
- Define reduction.
- List the raw materials used in the extraction of iron and their sources.
- Describe the reactions taking place in the blast furnace.
- List the functions of the raw materials used in the extraction of iron and their sources.
- Describe how iron and slag separate.

Introduction

Reactions with oxygen are usually called **oxidation** reactions and reactions in which oxygen is lost are called **reduction** reactions. The most common oxidation and reduction reactions are burning, rusting and respiration.

Long ago chemists did not have much knowledge about oxidation and reduction. They used these terms to describe reactions that involved oxygen (in burning, rusting and respiration) and hydrogen (in water formation) only.

Nowadays, **redox** processes (**reduction** and **oxidation**) are understood to include reactions that involve electron transfer.

Figure 14.1 Rusting is a reaction of iron with oxygen.

Oxidation and reduction in terms of hydrogen and oxygen

A substance is oxidised when it gains oxygen or loses hydrogen:

$S(s) + O_2(g) \rightarrow SO_2(g)$	Sulphur is oxidised to sulphur dioxide by gaining oxygen.
$H_2S(g) + Cl_2(g) \rightarrow 2HCl(g) + S(s)$	Hydrogen sulphide is oxidised to sulphur by losing hydrogen.

A substance is reduced when it loses oxygen or gains hydrogen:

$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$	Nitrogen is reduced to ammonia by gaining hydrogen.
$PbO(s) + H_2(g) \rightarrow H_2O_2(l) + Pb(s)$	Lead oxide is reduced by losing oxygen. (Hydrogen is oxidised to water by gaining oxygen.)

In redox reactions, the reduction and oxidation processes usually occur at the same time. That is, one substance is oxidised and another substance is reduced.

Example: $PbO(s) + H_2(g) \rightarrow Pb(s) + H_2O(l)$

The lead oxide has been reduced to lead and hydrogen has been oxidised to water. The reaction involves both oxidation and reduction.

Exercise 14.1

Which substances in the following reactions have been oxidised and which have been reduced?

1. $H_2O_2(g) + C(s) \rightarrow CO(g) + H_2(g)$
2. $Fe(s) + 4H_2O \rightarrow Fe_3O_4(s) + 4H_2(g)$
3. $Cl_2(g) + H_2(g) \rightarrow 2HCl(g)$
4. $SO_2(g) + 4Na(s) \rightarrow 2Na_2O(s) + S(s)$
5. $2Ca(s) + O_2(g) \rightarrow 2CaO(s)$
6. $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$

Oxidation and reduction in terms of electron transfer

In the reaction, $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$, the reactants, magnesium and oxygen, consist of neutral atoms, but the product (magnesium oxide) is ionic. It is made up of two ions of equal charges: Mg^{2+} and O^{2-}. To understand the reduction and oxidation in this reaction, we break it down into **half-reactions**. One half-reaction shows which reactant loses electrons and the other half-reaction shows which reactant gains electrons.

$Mg \rightarrow Mg^{2+} + 2e^-$ and $O_2 + 4e^- \rightarrow 2O^{2-}$

This loss-and-gain of electrons allows the atoms to gain the noble gas configuration. The half-reaction in which electrons are lost is called oxidation and the half-reaction in which electrons are gained is called reduction. You can use the following acronyms to help you remember:

- LEO: loss of electrons is oxidation
- GER: gain of electrons is reduction

In this example, the number of electrons gained by the oxygen atoms is exactly the same as the number lost by the magnesium atoms. The electron transfer occurs in equal numbers in all redox reactions. This means that electrons are not created or destroyed during a redox reaction. Note that redox reactions do not always involve oxygen; it is the loss and gain of electrons.

$2FeCl_2(s) + Cl_2(g) \rightarrow 2FeCl_3(s)$	$Cl_2 + 2e^- \rightarrow 2Cl^-$
Iron(II) chloride combines with chlorine to give iron(III) chloride.	Chlorine is reduced to chlorine ions by gaining two electrons.

- **Oxidising agents** are substances that promote other substances to be oxidised. They are reduced in a chemical reaction. Examples of oxidising agents include oxygen and chlorine.
- **Reducing agents** are substances that promote other substances to be reduced. They are oxidised in a chemical reaction. Examples of reducing agents are metals, carbon monoxide and hydrogen.

Exercise 14.2

1. Identify the substance that has been oxidised in each equation.
   a) $2Ag^+ + Mg(s) \rightarrow Mg^{2+} + 2Ag(s)$
   b) $Zn(s) + CuSO_4 \rightarrow Cu(s) + ZnSO_4(g)$
   c) $Fe(s) + 2H^+(aq) \rightarrow Fe^{2+} + H_2(g)$
   d) $H_2 + Cl_2 \rightarrow 2HCl$
2. Identify the substance that has been reduced in each equation in question 1.
3. Identify the reducing agents and oxidising agents in each reaction.
   a) $Mg(s) + 2HCl \rightarrow MgCl_2 + H_2$
   b) $H_2O(g) + C(s) \rightarrow CO + H_2(g)$
   c) $H_2S + Cl_2(g) \rightarrow 2HCl + S$

Experiment 14.1

Aim: To reduce copper(II) oxide using hydrogen

Materials: a reduction tube (boiling tube with small hole in closed end), a rubber bung for the reduction tube fitted with one glass tube, 3 g of copper(II) oxide (black copper oxide), hydrogen gas cylinder, rubber tubing, a retort stand and clamps, a Bunsen burner

Procedure

1. Place the copper(II) oxide in the reduction tube – spread it out as shown in Figure 14.2.

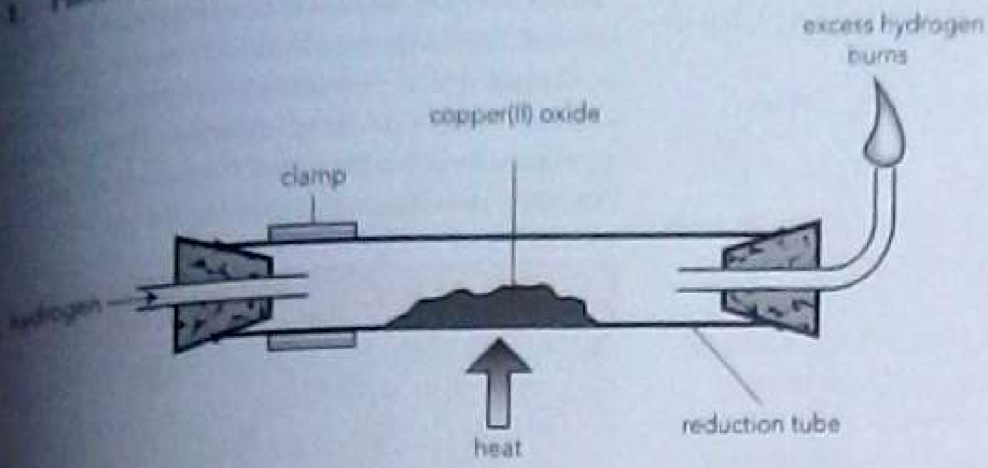


Figure 14.2 Reducing copper(II) oxide

2. Attach the rubber bung as shown and connect the glass tube to the hydrogen cylinder via the rubber tubing. Keep the apparatus horizontal and steady with the retort stand and clamps.
3. Open the valve on the hydrogen cylinder and make sure that the gas is flowing freely through the reduction tube.
4. Place the Bunsen burner below the reduction tube and switch it on. Stand back from the experiment.
5. Heat the copper(II) oxide until all of it has turned a pink colour. Heat for another minute or so, and then switch off the Bunsen burner and remove it from below the reduction tube.
6. Once the reduction tube is cool enough to touch, close the valve on the hydrogen cylinder.

Results

You should observe that the copper(II) oxide started to glow and then turned pink as it heated.

Questions

1. How do we know when the reduction reaction is complete?
2. Name the substance that is formed when copper(II) oxide is reduced.
3. What other substance may have been formed in this reaction? (Hint: Write a chemical reaction equation for this reaction.)

Oxidation numbers

Instead of writing half-reactions, we can use **oxidation numbers** to help us decide whether a redox reaction has occurred. When using this method, we assign an oxidation number to show how many electrons an atom of an element are being used in bonds with atoms of other elements. Changes in oxidation number during a reaction help us identify the atoms that lose and the atoms that gain electrons.

Rules for assigning oxidation numbers

These rules are used when oxidation numbers are assigned:

1. The oxidation numbers of all atoms (and monoatomic and diatomic elements) in their natural state is 0. For example, the oxidation number of atoms of Cl_2, Cu, Mg and H is 0.

2. The oxidation number of an atom in a simple monoatomic ion is the charge on that particular ion. For example, the oxidation number of a sodium ion (Na^+) is +1 and that of sulphur ion (S^{2-}) is –2.
3. The oxidation number of ions in Group 7 elements is always –1.
4. The oxidation number of oxygen in a compound is always –2, except when the compound is a peroxide or a superoxide.
5. Some elements have the same oxidation number in all their compounds. For example, Group 1 metals have an oxidation number of +1 in all their compounds, Group 2 metals have an oxidation number of +2 in all their compounds and hydrogen has an oxidation number of +1, except in metal hydroxides.
6. The sum of the oxidation numbers of all elements in a compound is 0, for example in MgO:
   $Mg^{2+} + O^{2-} \rightarrow MgO$
   (+2) + (–2) (0)
7. The sum of the oxidation numbers of all the elements in a radical is equal to the overall charge of that radical.

Exercise 14.3

1. Give the oxidation number of each atom in each substance.
   a) $MgCl_2$
   b) CO_2
   c) NaOH
   d) $KMnO_4$
   e) SO_3^{2-}
2. Assign the following oxidation numbers.
   a) N in KNO_3
   b) Cr in $K_2Cr_2O_4$
   c) Cu in Cu_2O
   d) S in Na_2SO_4
   e) Ba in $Ba(NO_3)_2$

The concept of oxidation numbers leads directly to a working definition of oxidation and reduction. Oxidation is an increase in oxidation number and reduction is a decrease in oxidation number.

Example: $CuSO_4(aq) + Zn(s) \rightarrow ZnSO_4(aq) + Cu(s)$

In this reaction, the oxidation number of copper in copper sulphate on the left side of the reaction is +2, but the oxidation number of copper on the right side of the reaction is 0.

This is a decrease in oxidation number, and therefore the compound copper sulphate has been reduced. Similarly, the oxidation number of zinc on the left side of the equation is 0, but it becomes +2 on the right side of the equation. The oxidation number of zinc has increased from 0 to +2 and therefore, zinc has been oxidised.

Exercise 14.4

1. In each case, state whether nitrogen has been oxidised or reduced.
   a) $N_2(g) \rightarrow HNO_3$
   b) $N_2(g) \rightarrow NH_3$
   c) $NO_2^- \rightarrow NO_3^-$
   d) $NH_4^+ \rightarrow NH_3$
   e) $NaNO_2 \rightarrow HNO_2$
2. Identify the oxidised substance in each reaction.
   a) $Fe + CuSO_4 \rightarrow FeSO_4 + Cu$
   b) $Cl_2 + 2KBr \rightarrow 2KCl + Br_2$
   c) $NaCl + AgNO_3 \rightarrow AgCl + NaNO_3$
   d) $2Al + 3Cl_2 \rightarrow 2AlCl_3$
   e) $CuO + C \rightarrow CO + Cu$
3. Identify the reduced substance in each reaction in question 2.

The extraction of metals

Most metals are found combined with other elements in the Earth's crust. Rock that contains these metal compounds is called ore. Examples of ore include rock salt (sodium ore), bauxite (aluminium ore) and copper pyrites (copper ores).

When an ore has been identified, it is broken into small particles and decomposed so that the pure metal can be retrieved. The process of separating the metal from impurities in the ore is called extraction.

Figure 14.3 Copper pyrite ($CuFeS_2$)

Methods of extracting metals

A number of methods are used to extract metals from their ores. How a metal is extracted depends on its position in the reactivity series and also on economic factors such as the cost of energy and the cost of the reducing agent.

- **Electrolysis**: Metals that are more reactive than zinc are usually extracted using electrolysis. However, this method uses a lot of electricity and thus it is expensive.
- **Reduction**: Metals that are less reactive than zinc are usually extracted by reducing the ore by heating it with carbon or carbon monoxide. Carbon is cheap and it can also be used as a source of heat. It is used to extract iron.
- **Roasting**: Some metals (such as copper) are relatively nonreactive. Copper is separated from sulphide by heating the ore in the air. This method removes sulphur in the form of sulphur dioxide gas. The copper that remains is separated from other metals by electrolysis.

Extracting iron

Iron is the second most abundant metal. The main ores of iron are haematite and magnetite.

In Zimbabwe, heamatite is concentrated in Kwekwe and Zvishavane. Iron is economically and industrially important for the following reasons:

- Iron ore is plentiful and easy to find in Zimbabwe.
- Reduction is used to extract iron; this method is relatively cheap.
- There is a wide range of uses for products that are made from iron.
- The by-products of the extraction process can be used in the road construction industry.

The raw materials in the extraction of iron are iron ore (in the form of iron(III) oxide), limestone (in the form of calcium carbonate ($CaCO_3$), and coke, which is refined coal (which does not contain a lot of impurities).

Iron ore, limestone and coke are mixed together to give a mixture called **charge**. Charge is fed into the top of a blast furnace (see Figure 14.4).

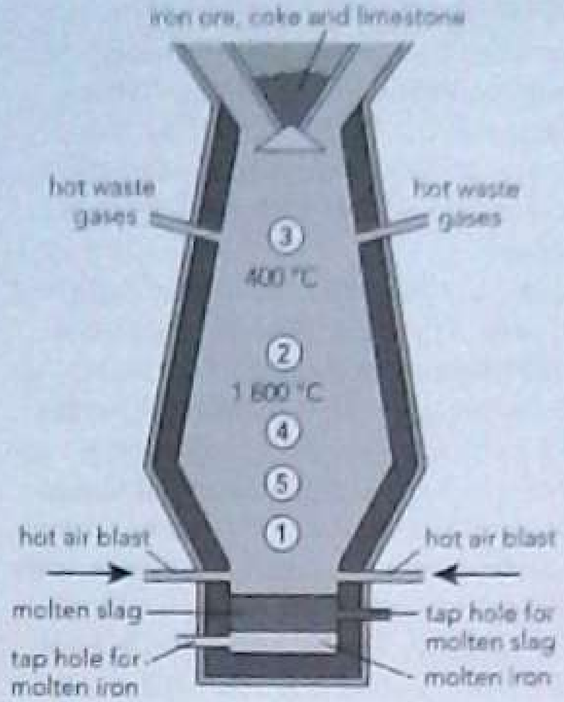


Figure 14.4 A blast furnace is used to extract iron from ore.

Air that has been heated in stoves to above 600 °C is pumped into the furnace. The following reactions occur:

1. The coke reacts with the oxygen in the air to produce carbon dioxide.
   $C + O_2 \rightarrow CO_2$
2. The carbon dioxide produced reacts with more coke. Carbon dioxide is reduced to carbon monoxide.
   $CO_2 + C \rightarrow 2CO$
3. Carbon monoxide reduces iron(II) oxide (Fe_2O_3) to form liquid iron, which trickles to the bottom of the blast furnace.
   $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$
4. Because of the high temperatures in the furnace, calcium carbonate decomposes to calcium oxide.
   $CaCO_3 \rightarrow CaO + CO_2$
5. The calcium oxide that is formed traps all the impurities. They are collected as **slag**.
   $CaO + SiO_2 \rightarrow CaSiO_3$
   The slag is lighter than the iron, therefore it floats on top of the iron. It is drained out as a liquid. The iron is tapped out of the furnace and used to make steel.

Conversion of iron to steel

The liquid iron that is collected from a blast furnace contains many impurities (including carbon, sulphur, silicon and phosphorus) that must be removed first. This liquid is called **pig iron**. Pig iron can be refined and processed and then cast into moulds. The final product is thus called cast iron.

Most of the pig iron that is collected is purified in a basic oxygen furnace. Recycled scrap iron is first put into the furnace and then the molten iron from the blast furnace is added. Pure oxygen is blown into the furnace through the oxygen lance. This converts the impurities (phosphorus, sulphur, carbon and silicon) to their oxides. Some of these oxides disappear as gases. To remove other impurities, quicklime (calcium oxide) is added. Quicklime combines with the impurities to form slag, which separates from the iron. Mild steel is produced from this basic oxygen furnace.

Figure 14.5 Blowing oxygen through the impure molten iron

Exercise 14.5

1. Name the raw materials that are added to the blast furnace when iron is extracted from ore.
2. Give the equations of all the major reactions that take place in the blast furnace.
3. What is the purpose of a basic oxygen furnace?

Summary

- Oxidation can be defined as the addition of oxygen, the loss of electrons, or an increase in oxidation number.
- Reduction can be defined as the removal of oxygen, the addition of hydrogen, or a decrease in oxidation number.
- An oxidation number is assigned to an atom or an ion to describe its relative state of oxidation or reduction.
- Oxidation numbers are calculated rather than measured experimentally.
- Metals are extracted from metal ore. The main ore from which iron is obtained is called haematite. Copper is extracted from chalcopyrite rock.
- The three most common methods that are used to extract metals are electrolysis, reduction and roasting.
- Electrolysis is a process in which electricity is used to split a compound into its constituent elements. Electrolysis is used to extract very reactive metals.
- Reduction involves using carbon or carbon monoxide to remove oxygen from oxide.
- The raw materials in the extraction of iron are iron ore, limestone and coke.

Glossary

charge – mixture of limestone, iron ore and coke in a blast furnace

half-reactions – equations that are used to show either the oxidation or reduction process of a redox reaction

ore – rock or mineral from which valuable substances (such as metals) can be extracted

oxidation – process that involves the addition of oxygen in a chemical reaction; it is also the removal of hydrogen or the loss of electrons during a chemical reaction

oxidation number – number assigned to an atom to show its relative oxidised or reduced form

oxidising agent – substance that oxidises another substance by removing some of its electrons

pig iron – crude iron produced in a blast furnace

redox reaction – reaction in which both an oxidation (loss of electrons) and a reduction (gain of electrons) occur

reducing agent – substance that reduces another substance by being oxidised

reduction – process that involves the removal of oxygen; also involves the addition of hydrogen or the gain of electrons

roasting – process of heating small particles of ore so that impurities are converted to gaseous oxides

slag – waste material that is left behind after metal has been smelted

Revision questions

1. Assign an oxidation number to each underlined element.
   - a) $Na_2\underline{O}$
   - b) $H\underline{N}O_3$
   - c) $Na\underline{N}O_3$
   - d) $\underline{Cu}_2O$
   - e) $\underline{Cu}O$
   - f) $K\underline{Mn}O_4$ (6)
2. Is the underlined atom oxidised or reduced?
   - a) $\underline{Na} \rightarrow NaCl$
   - b) $\underline{N}_2 \rightarrow NH_3$
   - c) $\underline{Mn}O_4^- \rightarrow MnO_2$
   - d) $\underline{Fe}O \rightarrow Fe$ (4)
3. Iron(II) oxide reacts separately with sulphuric acid and carbon according to the following equations.
   - A. $FeO(s) + H_2SO_4(aq) \rightarrow FeSO_4(aq) + H_2O(l)$
   - B. $FeO(s) + C(s) \rightarrow Fe(s) + CO(g)$

   Which of these reactions is a redox reaction? (2)
4. Give the following in the redox reaction you identified in question 3:
   - a) the substance that has been oxidised (1)
   - b) the number of electrons that are transferred. (1)
5. In terms of electron transfer, define the following terms.
   - a) reduction (2)
   - b) oxidation (2)
6. Answer the questions with regard to the following reaction: $Mg(s) + Cl_2(g) \rightarrow MgCl_2(s)$.
   - a) How many electrons are lost by the magnesium? (1)
   - b) How many electrons does each chlorine atom gain? (1)
   - c) Which is the oxidising agent and which is the reducing agent in the reaction? (2)
7. The production of iron in a blast furnace is a continuous process. The production of steel in a basic oxygen furnace is a batch process.
   - a) Explain what is meant by the terms 'continuous process' and 'batch process'. (2)
   - b) Suggest one advantage of a continuous process and one disadvantage of a batch process. (2)
8. Iron is extracted from its ore in a blast furnace. Use equations to explain the reactions that take place when limestone is added to the mixture in the furnace. (6)
9. Explain how you would convert pig iron into steel. (3)

TOTAL: 35

Unit 15 Organic chemistry

Objectives

- Define the term 'hydrocarbon'.
- Name the members of the homologous series of alkanes and alkenes with up to three carbons.
- Draw the displayed structures of methane, ethane, propane, ethene, propene.
- Outline the production of biogas.
- Identify factors affecting the production of biogas.
- List the uses of biogas.

Introduction

Organic chemistry deals with the chemistry of compounds that contain carbon. Organic compounds can occur naturally, but they can also be synthesised, that is, produced artificially.

Organic molecules always contain carbon atoms that are covalently bonded to other carbon atoms or hydrogen atoms. These compounds play an important role in our lives.

Natural organic compounds make up all living things. They are present in human and animal bodies, in plants and in food. Mixtures of organic compounds are also present in fossil fuels. For example, coal, crude oil and natural gas were all once living things. Synthetic organic compounds include synthetic fibres, plastics, dyes and drugs.

Organic molecules

The study of the millions of organic compounds has been made easier because they tend to fall into families, which are characterised by a **functional group**. A functional group is a particular group of atoms that gives an organic molecule its physical and chemical properties. Organic molecules range from molecules with only one carbon atom to molecules with long chains of covalently bonded atoms, branched chains or even ring structures. Atoms such as oxygen, chlorine and bromine can attach to these rings and chains. These groups are the functional groups. A family of compounds that has the same functional group is called a **homologous series**. Members of a homologous series have similar properties because the atoms making up these molecules are bonded in a similar way.

The table below shows the functional groups of the main classes of organic molecules.

Functional group	Class of compound	Example of molecule
–H–C– (single bonds)	alkane	CH_3CH_3
>C=C<	alkene	$CH_2=CH_2$
–C≡C–	alkyne	$HC\equiv CH$
–C–OH	alcohol	CH_3OH
–C–O–C–	ether	CH_3OCH_3
–C(=O)–OH	carboxylic acid	$CH_3C(=O)OH$
–C(=O)–O–C–	ester	$CH_3C(=O)OCH_3$

Hydrocarbons

Organic compounds are classified according to the elements they contain and how these elements are bonded together. For example, **hydrocarbons** consist of only hydrogen and carbon. Hydrocarbons are further divided into **alkanes**, **alkenes** and **alkynes**. Alkanes, alkenes and alkynes are examples of homologous series. Members of a homologous series have the same functional group and a general formula. The general formula of alkanes is C_nH_{2n+2} with $n = 1, 2, 3, \ldots$ and for alkenes with one double bond it is C_nH_{2n} with $n = 2, 3, \ldots$ You have to know the names of the members of these two series up to $n = 3$.

Naming hydrocarbons

Names for organic compounds can look quite complicated, but they are no more than a code that describes the molecule. One part of the name tells you how many carbon atoms there are in the longest chain, another parts tells you whether there are any carbon–carbon double bonds, and so on.

The chain length

The code letters for the number of atoms in a chain are given in the table below.

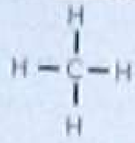
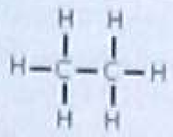
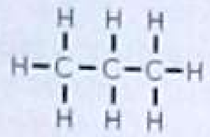
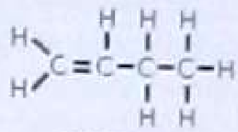
Code letters	Number of C atoms in chain
meth-	1
eth-	2
prop-	3
but-	4
pent-	5
hex-	6

Type of compound

Alkanes are hydrocarbons in which all the carbons are joined to each other with single covalent bonds. These compounds all end in -ane.

Alkenes are also hydrocarbons, but this family of molecules contain a carbon–carbon double bond. This is shown in their name, which ends in -ene. The position of a double bond is found by numbering the chain and noting from which carbon atom the double bond starts.

The names and structures of the hydrocarbons that you need to be familiar with in Form 3 are shown in the table that follows.

Alkanes	Alkenes
 methane	none
 ethane	 ethene
 propane	 propene

Exercise 15.1

1. Explain what a hydrocarbon is.
2. Draw the functional group of the alkenes.
3. In groups, and using molecular kits, build models of the following hydrocarbons:
   a) ethane b) ethene
   c) propane d) propene

Biogas in Zimbabwe

The alkanes are commonly used as fuels because they are highly combustible. However, they are expensive to produce from crude oil resources.

In Zimbabwe, a national programme in support of the construction and use of **biogas** plants has helped to improve the lives of many Zimbabweans through providing clean energy for cooking, a sustainable waste management system and potentially, an increase in household income – all through the simple yet efficient technology of biogas production.

The production of biogas

The role of bacteria

Many kinds of bacteria are **anaerobic**. This means that they do not require oxygen to respire. Some produce alcohol, others lactic acid. Some of these bacteria are useful to us. For example, those that produce lactic acid are used for making butter, yoghurt and cheese. Lactic acid that forms through fermentation of milk sugar (lactose) curdles milk, making it go lumpy. This is the first stage in the formation of these dairy products.

Certain bacteria produce methane gas as the end product of anaerobic respiration. These bacteria thrive in situations where there is no oxygen, such as stagnant ponds, waterlogged soil, and sewage. They too are useful to us. The methane they produce can be used as biogas. The biogas burns well and is used to drive the machinery in modern sewage works.

Biogas contains mostly methane gas, but also some carbon dioxide and sometimevs, small amounts of hydrogen sulphide and moisture.

Typically, animal and plant waste is fermented by anaerobic bacteria in special biogas digesters. The gas collected is used for cooking, lighting, and other energy-requiring processes.

The role of temperature

Some bacteria thrive under temperature conditions of between 30 and 38 °C. These bacteria are called mesophiles. Others, known as thermophiles, prefer higher temperatures of between 50 and 60 °C. Depending on the temperature that can be maintained in a biogas digester, either the mesophiles or the thermophiles will do the work. Mesophilic systems are typically more stable and thus safer, but do not produce as much biogas as thermophilic systems.

The role of pH

pH plays quite an important role in the production of biogas in terms of keeping the organisms that produce the biogas healthy. Most methane-producing bacteria thrive in a pH environment of between 7 and 8, which means they enjoy a slightly alkaline environment. A more acidic environment allows for the growth of other (unwanted) organisms, and impacts the production of compounds such as ammonia and organic acids, which also play a role in the production of biogas.

Biogas digesters

Most household biogas digesters are constructed below ground level, although some types do protrude from the ground. The reservoir typically has a capacity of six to eight cubic metres.

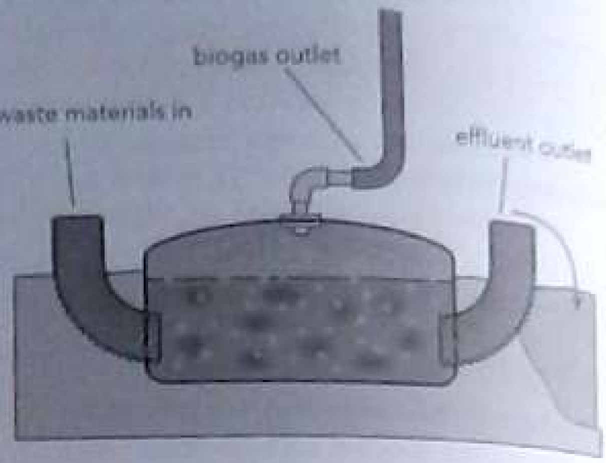


Figure 15.1 A household biogas reactor

Household and animal wastes are introduced to the biogas digester on the left in Figure 15.1. Once inside the reservoir, the bacteria start to digest the wastes. As this happens, the biogas (methane) rises to the top of the reservoir, where the gas can be piped into the household again to be used as fuel for cooking, heating and lighting. The effluent (that which is left over once the bacteria have converted as much methane from the waste as possible) makes an excellent – and clean – fertiliser which can be used on farms and in gardens.

Activity 15.1

In groups of four or five, do some research about household or community-based biogas reactors in Zimbabwe.

1. Find out how they:
   a) are constructed. (Are special materials or tools needed? Is it expensive to build such a reactor?)
   b) produce biogas.
2. Using recyclable waste products (such as cardboard and plastic), build a model of a biogas digester.

Other factors that affect the production of biogas

As mentioned, bacteria, temperature and pH can affect the volume of biogas produced, but a number of other factors also play a role:

1. **Type of input material.** The ratio of carbon to nitrogen in the input materials determines the quality of that material in terms of biogas production. Cattle dung and pig manure are excellent in this regard, but certain plant materials can also produce very good yields.
2. **The presence of toxic substances in the input material.** Traces of fertilisers, pesticides and antibiotic treatments (for farm animals) remain in the waste that is used in the biogas digester. Some of these can have a toxic effect on the system, and can therefore limit the amount of biogas produced.
3. **How airtight the biogas digester is.** Any leaks in the reactor can allow air, and therefore oxygen into the system. The anaerobic processes that produce the biogas cannot occur in the presence of oxygen.
4. **The presence of moisture.** The bacteria need a considerable amount of moisture in order to produce biogas. For household systems, about half of the volume of the biogas digester needs to be water, with only 40% of it filled with input material and the remaining 10% available for the biogas to collect.

Uses of biogas

The methane gas that is produced in a biogas digester is primarily used as a household fuel in Zimbabwe. Gas stoves allow for a much cleaner heat source than burning wood, as methane does not produce any ash. At the same time, methane is a fuel-efficient gas, so a small volume of gas can produce a relatively large amount of heat.

Similarly, heating and lighting systems that use biogas are more convenient – and healthier – than those that rely on charcoal, wood or paraffin. Since the fuel is produced for free, there is also a considerable cost benefit to using biogas.

Because biogas digesters make use of agricultural waste products, the risk of dangerous pathogens from animal waste to humans is minimised.

In developed countries, methane gas is used on a large scale to produce electricity.

Summary

- Organic chemistry involves the study of compounds that are derived from organic matter. It also involves the study of synthetic plastics, dyes and drugs.
- A homologous series is a family of organic compounds that follows a particular trend in its physical and chemical properties.
- A functional group is a particular group of atoms that gives an organic molecule its physical and chemical properties.
- Alkanes have names that end in -ane. Alkanes burn in oxygen to give carbon dioxide and water.
- Alkenes form a homologous series and their names end in -ene.
- An alkene molecule has at least one double bond in its chain.
- Biogas is a sustainable, renewable fuel that is easily produced from household and agricultural waste.
- The primary component of biogas is methane.

Glossary

alkane – a hydrocarbon that only contains single bonds between carbon atoms
alkene – a hydrocarbon that contains at least one double bond between two carbon atoms in its chain
alkyne – a hydrocarbon that contains at least one triple bond between two carbon atoms in its chain
anaerobic – does not require oxygen to respire
biogas – a natural gas that is produced by the fermentation of organic matter
functional group – a particular group of atoms that gives an organic molecule its properties
homologous series – series of organic molecules in which each molecule differs from the next by the addition of the same group of atoms each time
hydrocarbon – organic compounds that contain only hydrogen and carbon

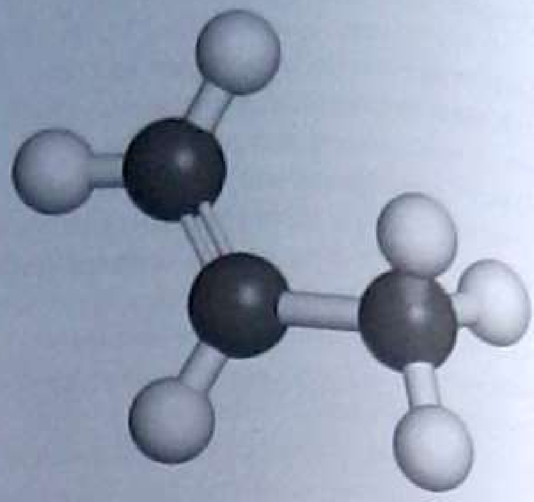


Figure 15.2 CH_2CHCH_3 (propene)

Revision questions

1. Ethane has the following structure:
   A. CH_2CH_2
   B. CH_3CH_3
   C. CH_3CH_3
   D. CH_4 (1)
2. Which one of the following organic molecules is not a hydrocarbon?
   A. CH_2ClCH_3
   B. CH_3CH_3
   C. $CH_3CH_2CH_3$
   D. $CH_3CH_2CH_2CH_2CH_3$ (1)
3. Answer the questions about hydrocarbons.
   a) What is a hydrocarbon? (2)
   b) Name two homologous series that are hydrocarbons. (2)
4. Give the molecular and structural formulae of alkanes with the following number of carbons.
   a) 3
   b) 4
   c) 6 (6)
5. Consider the organic substance called biogas.
   a) Explain what biogas is. (2)
   b) Name three factors that play an important role in the production of biogas. (3)
   c) Draw a simple labelled diagram to show the main parts of a biogas digester. (3)

TOTAL: 20

End of topic revision test

1. A piece of metal is heated so that it becomes warm but does not melt. Which statement is correct?
   - A The bonds holding the metal atoms together start to break.
   - B The metal atoms start to move around freely.
   - C The metal atoms start to vibrate more rapidly.
   - D Some metal atoms can escape from the surface of the metal. (1)
2. An ion's oxidation number:
   - A is always constant
   - B is the same as its number of valence electrons
   - C must always be zero
   - D indicates the charge on the ion. (1)
3. Avogadro's number tells us:
   - A the number of particles in one mole of substance
   - B the number of atoms in 1 g of carbon-12
   - C the volume that one mole of a substance occupies
   - D the number of protons in an atom. (1)
4. In which group in the Periodic table are the alkaline earth metals found?
   - A Group 1
   - B Group 2
   - C Group 17
   - D Group 18 (1)
5. The liquid that is collected in the beaker after passing through the condenser during simple distillation is called:
   - A the filtrate
   - B the solvent
   - C the distillate
   - D the first fraction. (1)
6. Give one word or term to describe the following:
   - a) does not require oxygen to respire
   - b) the crude iron that is produced in a blast furnace
   - c) the electrode at which reduction takes place during electrolysis
   - d) a substance that changes colour according to the acidity or alkalinity of the solution it is in
   - e) atoms of the same element that differ only in the number of neutrons that they contain
   - f) a measure of an amount of substance (6)
7. Explain the relationship between the mass of a sample of substance and the number of particles that are found in that sample. (3)
8. Which gas is evolved when a dilute acid reacts with a carbonate? (1)
9. Draw the electronic configuration diagram for silicon. (3)
10. A soluble metal oxide solution and a potassium hydroxide solution both turn red litmus blue and they have a soapy feel. What other properties would you expect these substances to have in common? (2)
11. Assign an oxidation number to each underlined element.
    - a) $K_2\underline{Cr}_2O_7$
    - b) $\underline{N}H_3$
    - c) $\underline{Cl}O_3^-$
    - d) $\underline{C}O$ (4)
12. State whether the underlined atom is oxidised or reduced.
    - a) $\underline{Fe}O \rightarrow Fe_2O_3$
    - b) $\underline{C}O \rightarrow CO_2$
    - c) $\underline{Mn}Cl_2 \rightarrow MnO_4^-$ (3)
13. Some mixtures of liquids can be separated using the method of fractional distillation.
    - a) When would a scientist choose to use fractional distillation instead of simple distillation? (2)
    - b) Draw a simple sketch to show the apparatus used in fractional distillation. (5)

14. The components of two washing powders, X and Y, are listed in the table below.

Component	Powder X (%)	Powder Y (%)
sodium sulphate	0	35
sodium carbonate	30	0
sodium silicate	20	26
sodium soap	12	14
detergent	18	13

Dilute aqueous solutions of washing powders X and Y are made and filtered. Portions of these filtered solutions are acidified with dilute nitric acid and then barium chloride solution is added.

a) Write down what you observe for each powder. (2)

b) Explain your observations. (2)

15. Consider the electrolysis of copper sulphate.

a) Draw a well-labelled diagram to illustrate this process. (4)

b) Describe and explain what happens during this process:

i) at the anode (1)

ii) at the cathode. (1)

16. Iron ore is refined to usable iron in a blast furnace.

a) Draw a diagram of a blast furnace, clearly showing where air is blasted into the furnace, where the molten iron is removed and where the second liquid is removed. (5)

b) Name three raw materials that are added at the top of the furnace. (3)

c) What is the purpose of the different raw materials of iron extraction? (3)

d) Give the name of the second liquid that is removed from the bottom of a furnace. (1)

17. a) In which homologous series does the molecule $CH_3CH_2CH_3$ belong? (1)

b) Draw diagrams to show the bonding in methane and ethane. (4)

18. Explain how temperature affects the production of biogas in a biogas digester. (4)

TOTAL: 65

Unit 16 Data presentation

Objectives

- Interpret and analyse data from pie charts and line graphs.

Introduction

Graphs allow us to represent **data** or information in a way that is easy to understand. You have learnt how to present data in various forms, including bar graphs and line graphs. Both of these types of graphs represent one set of data in relation to another set of data. But what if you wanted to express data as a percentage of the total data collected?

Drawing bar and line graphs

Exercise 16.1

The average rainfall (in mm) of a region over a number of months is represented in the table below.

Month	Average rainfall (in mm)
January	40
February	50
March	45
April	35
May	20
June	10

Presenting the month on the x-axis and average rainfall in mm on the y-axis:

1. Draw a bar graph.
2. Draw a line graph.

Pie charts

Pie charts, also called circle charts, shows one set of data as a percentage of the total. The data in the table of Exercise 16.1 is represented in Figure 16.1 in pie chart form.

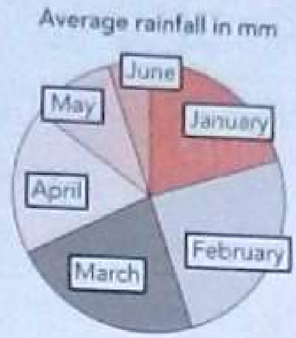


Figure 16.1 A pie chart representing average rainfall in January to June

Drawing a pie chart from given data

Let us first do an activity to see how data can be presented in the form of a pie chart.

Activity 16.1

Aim: To draw a pie chart from the data in Exercise 16.1

Materials: paper, a pencil, a protractor, a calculator

Procedure

1. Calculate the percentage of your data relative to the total.
   For the information above:
   The percentage for June
   = average rainfall in June ÷ the total rainfall over 6 months
   $= \frac{10 \text{ mm}}{200 \text{ mm}} \times \frac{100}{1}\%$
   $= 5\%$
2. Use the percentage to calculate which portion of a circle it should be by multiplying the percentage by 360°.
   In the example that would be
   $5\% \times 360° = 18°$.

3. Draw a circle and find its central point. Draw a radius line from the centre to the edge of the circle.
4. From your radius line, mark out 18° and draw a second radius line to that point.
5. Repeat steps 1 to 4 for all the months.

Results

Your pie chart should resemble the first chart in Figure 16.1.

When you look at the graph, you should be able to tell very easily that the lowest rainfall is in the months of May and June. You must also notice that nearly half of all the rainfall during this time is in the months of March and April.

Interpreting data presented in pie charts

Pie charts are visually appealing and, because of their presentation, easy to understand. However, bar and line graphs present more information and are therefore more useful.

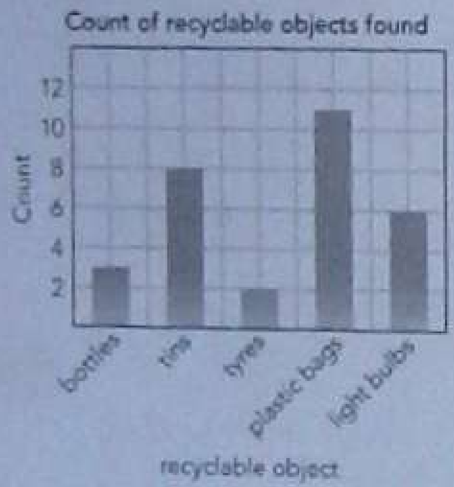


Figure 16.2 An example of a bar graph

Exercise 16.2

Refer to Figure 16.2 below and answer the questions that follow.

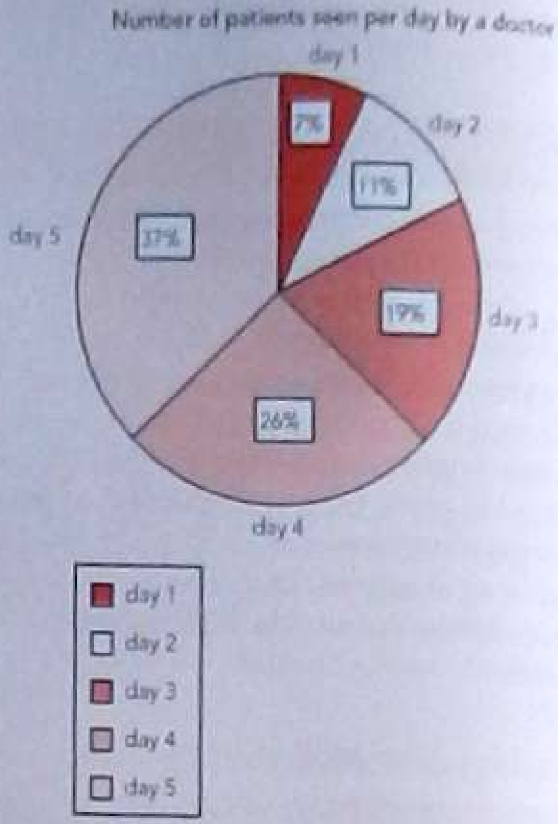


Figure 16.3

1. What is represented by the chart?
2. On which day did the doctor see the fewest patients?
3. On which day did the doctor see the most patients?
4. Are you able to calculate the number of patients seen on day 4? What additional information do you need to calculate the number of patients seen?

Summary

- Graphs allows us to present data in a way that is easy to read.
- Pie charts show data as a percentage of the total data collected.
- Line and bar graphs give more information than pie charts, so that the information you want to show may influence the type of graph you choose to draw.

Glossary

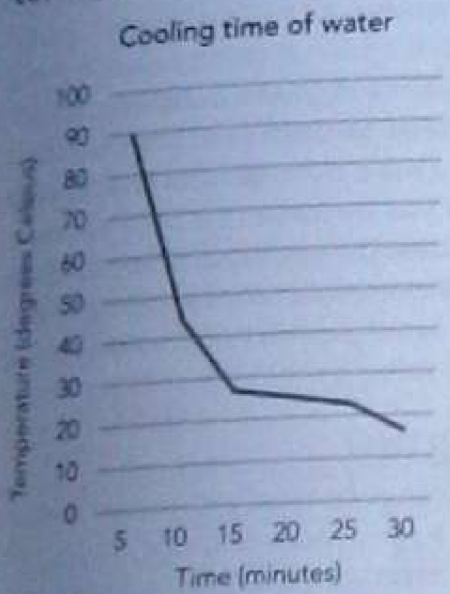
chart – a way to represent information in picture form

pie chart – a chart representing data in a circle form

data – a collection of information

Revision questions

1. Answer the following questions about this line graph showing data gathered for an experiment with the aim to examine the cooling time of water.



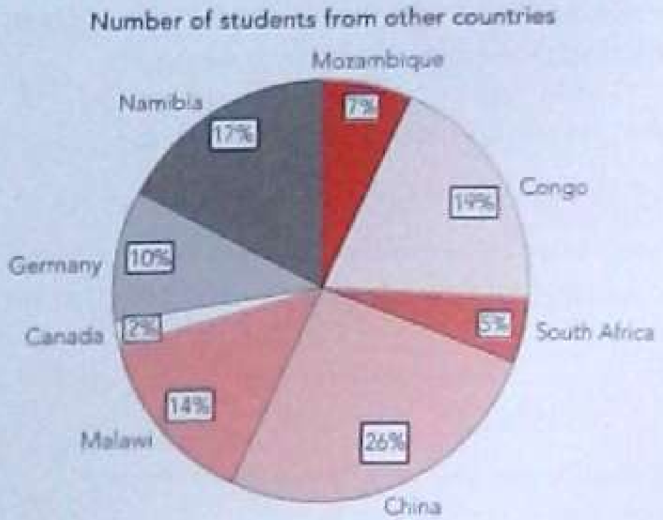
a) At what temperature was the water when the experiment started? (1)

b) How long does it take for the water to cool to below 50°C? (1)

c) How long does it take for the water to cool to below 20°C? (1)

d) How long did this experiment take? (1)

2. A learner in your school collected data on the numbers of learners coming from countries other than Zimbabwe.



a) From which country do the most foreign learners come? (1)

b) From which country do the fewest foreign learners come? (1)

c) Work out the percentage of learners who are not from Africa. (1)

d) If there are 42 learners from other countries in your school, calculate the number of learners from Mozambique. (2)

TOTAL: 9

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Unit 17 Measurement

Objectives

- Measure physical quantities accurately, using appropriate instruments.
- Read the scale on measuring instruments to the nearest fraction of the division.
- Determine the density of liquids as well as of irregularly shaped objects.

Introduction

Taking measurements is an integral part of all scientific investigation. Accuracy in taking these measurements is vital to make sure that the findings of investigations and experiments are correct.

The first part of accurate measurement is selecting the appropriate instrument to use.

Measuring instruments

In the first part of this unit, you will be introduced to different instruments of measurement and how to use them.

Activity 17.1

Aim: To practise taking measurements and recording them in a table

Materials: objects to measure (a page, a book, an eraser, a pencil, and so on), a ruler or measuring tape

Procedure

1. Using the ruler or measuring tape, measure the different objects.
2. Record your measurements in a table, showing the objects you measured and the unit of measurement.
3. Now compare your results to those of two other learners in your class.

Results

Were your measurements the same as those of both your classmates? If there were differences, why do you think you got different results than your classmates did?

Instruments for measuring length

The SI unit for measuring length is the metre (m). Here are some instruments commonly used to measure length.

Ruler

A rigid piece of wood, plastic or Perspex with markings as small as 1 mm or as large as 1 cm. When using a ruler, try to get it as close as possible to the object you are measuring. Your eye must be directly above the reading in order to measure correctly. (Remember to take the appropriate measures to avoid parallax errors whenever you use an analogue scale.)

Measuring tape

A flexible piece of material with similar markings to those on a ruler. Measuring tape can be used to measure objects that are not flat or straight, such as the circumference of a pipe.

Vernier callipers

A tool that is used for taking highly accurate measurements. It has two scales, a main scale with markings similar to those on a ruler and a Vernier scale with markings in 0.1 mm increments.

Vernier callipers are especially useful when measuring the diameter of objects such as pipes.

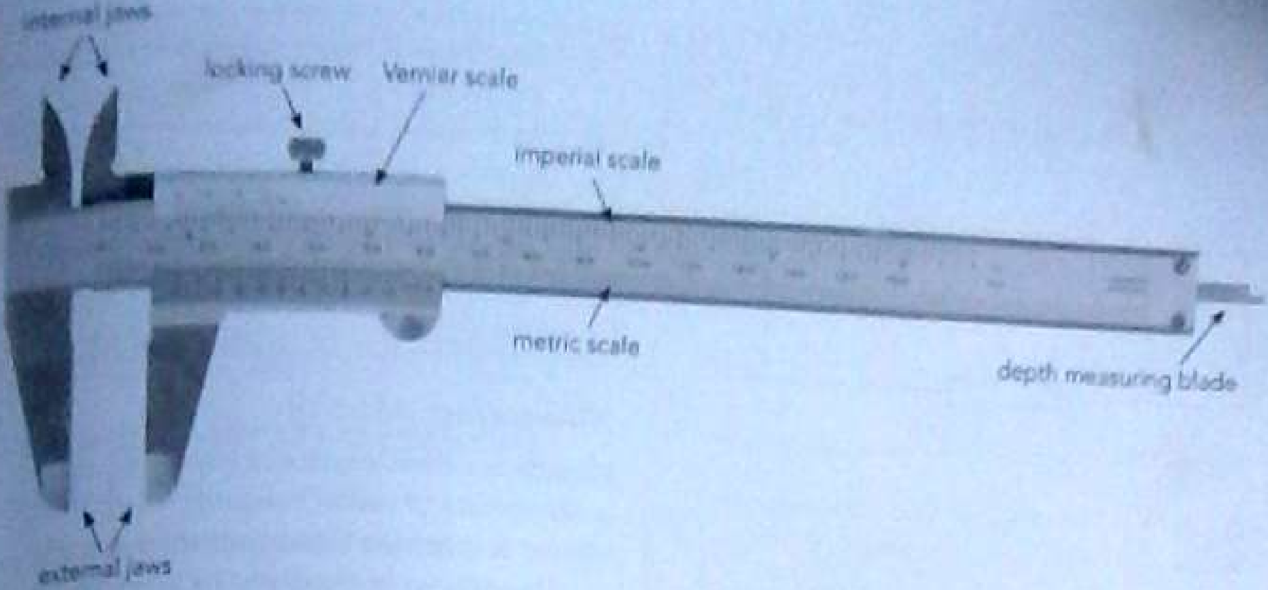


Figure 17.1 Vernier callipers

How to use Vernier callipers

1. Close the jaws to allow for zero errors.
2. Open the jaws slowly to fit the object firmly.
3. Take the measurement, first reading from the main scale and then from the Vernier scale.
4. Record the measurement.

The next activity will give you a chance to practise your skills at taking precise measurements with Vernier callipers.

Activity 17.2

Aim: To practise taking measurements of length by using Vernier callipers and recording the measurements

Materials: the same objects to measure as before (for example, a page, a book, an eraser, a pencil), but use Vernier callipers instead of a ruler or measuring tape

Procedure

1. Repeat the measurement of the objects you examined in Activity 17.1, but this time use Vernier callipers.
2. Once again, record your measurements in a table. Then compare them to the measurements of two other classmates.

Results

How much difference was there between the measurements of the different classmates, as compared to the measurements taken in Activity 17.1?

Vernier callipers are highly accurate.

Instruments for measuring electricity

Being able to measure different aspects of an electrical circuit is important in the safe application of electricity.

Ammeter

An **ammeter** measures the strength of an electrical current, that is, how many charges move through a circuit per second. The reading is in ampere (A). An ammeter is a very sensitive instrument and is always connected in series in a circuit.

Activity 17.3

Aim: To measure and compare the strength of current in a given circuit when adding resistors or adding cells

Materials: 2 to 3 cells, a cell holder, insulated copper wire, small light bulbs or other resistors, an ammeter

Procedure

1. Set up a circuit as shown in the following circuit diagram.

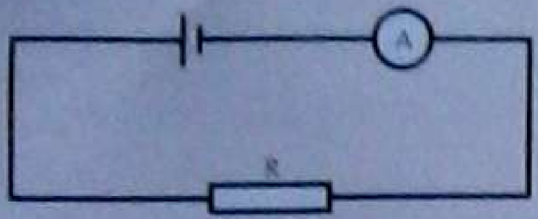


Figure 17.2 Circuit with ammeter and resistor

2. Take the reading from the ammeter.
3. Add another bulb or resistor and take the ammeter reading again. How has the reading changed?
4. Add another cell and take the ammeter reading again. How has the reading changed?

Voltmeter

A **voltmeter** is used to measure a cell's ability to transfer energy, or, the **potential difference** of cells. A voltmeter is always connected in parallel. The SI base unit for potential difference is the volt (V).

Activity 17.4

Aim: To measure and compare the potential difference in a given circuit when adding resistors or adding cells

Materials: 2 to 3 cells, a cell holder, insulated copper wire, small light bulbs or other resistors, a voltmeter

Procedure

1. Set up a circuit as shown in the following circuit diagram.

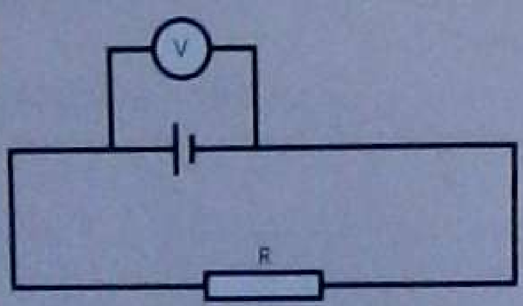


Figure 17.3 Circuit with voltmeter and resistor

2. Take the initial reading from the voltmeter and record it.
3. Add another bulb or resistor and take the voltmeter reading again. How has the reading changed?
4. Add another cell and take the voltmeter reading again. How has the reading changed?

Measuring density

Density is a measurement of how much mass a given volume of matter contains. The SI unit of density is grams per cubic centimetre (g/cm^3).

Density can be calculated by dividing the mass of an object by its volume. This is relatively easy when dealing with solid objects that are in perfect geometrical shapes.

Determining the density of a liquid

When determining the density of a liquid, we first have to determine both its volume and its mass. By pouring the liquid into a measuring cylinder, we can convert the measurement to determine volume. The following is true for all liquids:

1 mℓ of liquid = 1 cm^3 in volume of the liquid

The following activity will give you practice in determining the density of liquids of different densities.

Activity 17.5

Aim: To calculate the density of different liquids

Materials: different liquids to measure (water and vegetable oil, for example) a balance, one or two measuring cylinders

Procedure

1. Weigh the measuring cylinder and record its mass, in grams, as accurately as possible.
2. Take the measuring cylinder off the balance. Carefully pour in water until the level is as close to the 10 mℓ mark as possible.
3. Put the measuring cylinder back on the balance. Measure and record the new mass (cylinder plus water), in grams.

4. Subtract the two measurements of mass from one another.
5. Divide the result in Step 4 by 10 cm^3 to calculate the density of the water.
6. Using vegetable oil this time, repeat steps 1 to 5.

Results

Which of two liquids has the highest density?

Calculating the density of irregularly shaped objects

The difficulty in determining the density of irregularly shaped objects lies in determining its volume. By contrast, the dimensions of regular geometric shapes can be measured easily and used to calculate their volume.

The volume of an irregularly shaped object can be found by submerging it in water in a measuring cylinder or jug and by recording how much water is displaced. The volume of the displaced water is equal to the volume of the object.

Activity 17.6

Aim: To determine the density of irregularly shaped objects

Materials: water, a balance, a measuring cylinder, different irregularly shaped objects (such as small stones)

Procedure

1. Weigh the irregularly shaped objects and record their mass, in grams, as accurately as possible.
2. Pour enough water in the measuring cylinder to submerge the object completely. Take the reading. (You can fill it up carefully to a convenient calibration mark.)
3. Submerge the object.
4. Record the new level of water.
5. Subtract the second reading from the first to get the volume of the irregular object.
6. Divide the mass by the volume to get the density of the material of the object.
7. Using different objects, repeat steps 1 to 6.

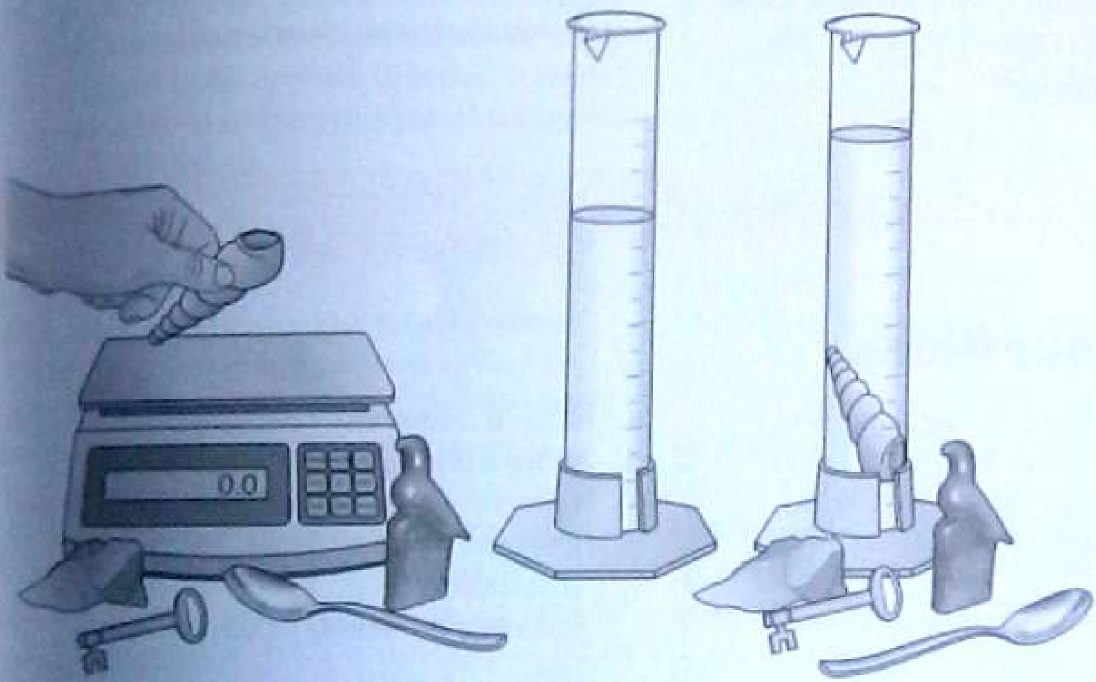


Figure 17.4 You can determine the density of an irregularly shaped object by finding its mass and by measuring the volume of water it displaces.

Summary

- Taking accurate measurements is essential in science in order for results of experiments to be valid.
- Vernier callipers are incredibly sensitive instruments and must be treated with care.
- Vernier callipers are very useful when accurate measurements are needed.
- An ammeter measures the strength of an electrical current, that is, how many charges move through a circuit per second.
- An ammeter is always connected in series.
- A voltmeter is used to measure a cell's ability to transfer energy, or, the potential difference of cells.
- A voltmeter is always connected in parallel.

Glossary

ammeter – a measuring instrument used to find the strength of the electrical current flowing through a circuit

density – how much matter is contained in a given volume

potential difference – the difference in electric potential between two points or objects

Vernier callipers – a special measuring instruments for taking accurate length measurements

voltmeter – a measuring instrument used to find the potential difference within a circuit by connecting it in parallel

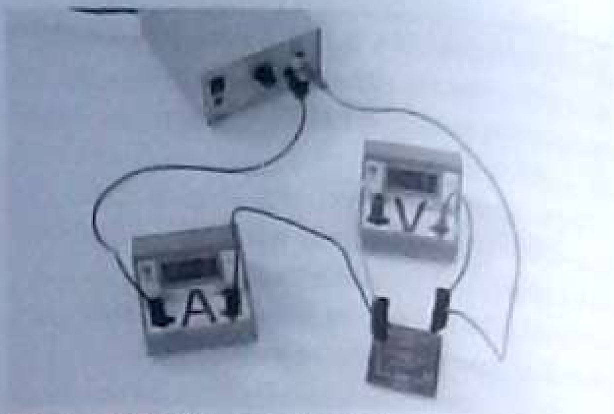


Figure 17.5 An ammeter is always connected in series while a voltmeter is connected in parallel

Revision questions

1. Describe how to use Vernier callipers to measure the internal diameter of a pipe. (2)
2. Why is it better to use Vernier callipers than an ordinary ruler to take some measurements? (3)
3. How should an ammeter be connected in a circuit? (2)
4. What is measured by a voltmeter? (1
5. When a lead sinker was lowered into a measuring cylinder with water, the water level rose from 35 mℓ to 42 mℓ. The mass of the lead sinker is 79 g. Calculate the density of the lead sinker. (4

TOTAL: 1

Unit 18 Force

Objectives

- Define weight, momentum and inertia.
- Explain Newton's laws of motion.
- Given an object's mass and acceleration, calculate the force exerted on it.

Introduction

When two people shake hands, they interact. Pairs of objects can also interact. Just as with a handshake, each object is an equal partner in the interaction.

When objects interact, we say they exert a force on each other. Since force has a magnitude and direction, it is a vector. Because the interacting objects are equal partners, the force each one exerts on the other has the same size, but the directions are opposite. In other words, as object A exerts a force on object B, object B exerts an equal force on A, but in the opposite direction. It is not possible for only one object in a pair of interacting objects to exert a force.

Newton's first law of motion

In the 1600s, a British scientist, Isaac Newton, realised that no net force is required to keep an object moving in uniform motion. In other words, movement in uniform motion (movement at a constant speed in a specific direction) is a natural state for all objects. An object in uniform motion will thus remain in uniform motion, unless something makes it change its motion. An external force is needed to cause a change in motion.

From experience you know that, even when you roll a smooth ball along a smooth surface, it will eventually slow down and stop. It is the force of **friction** (an external force) that causes it to stop moving.

Imagine for a moment that friction was absent, then the pushed body will continue moving at the same speed and in the same direction forever. Such a system is called an isolated system. Newton's first law applies to an isolated system and can be summarised as follows.

Every object continues in its state of rest or uniform motion in a straight line unless it is acted on by an external force.

Newton's second law of motion

We can use Newton's second law of motion to relate changes in an object's motion to forces that act on the object.

The next two experiments will help you develop techniques that are necessary to study aspects of motion. Experiment 18.1 will teach you how to measure time with a ticker timer while Experiment 18.2 will teach you to calculate the acceleration of a moving body.

Experiment 18.1

Aim: Using a ticker timer to measure time

Materials: a ticker timer, ticker tape, a stopwatch or stop clock, a mechanics trolley or wind-up/pull-back toy car (optional)

Procedure

1. Thread a short length of ticker tape through the ticker timer. If there is a carbon paper disc, make sure the tape goes underneath the disc.
2. Turn the ticker timer on for a few seconds. It vibrates rapidly and hits the top of the carbon paper. It makes a lot of dots on the tape, at regular intervals.
3. Remove the tape from the ticker timer. If the tape didn't move when the ticker timer was switched on, then all the dots will be in the same place.
4. Thread a longer piece of ticker tape, about 1 metre long, through the ticker timer. Switch the ticker timer on. Pull the tape slowly through the ticker timer.
5. Check the tape to see if you can see each individual dot, with a space between. We can say that each dot-to-dot space stands for a 'tick' of time.
6. Thread another 1 metre piece of tape through the ticker timer.
7. You need a 'start' signal and a 'stop' signal. These could be hand-claps by one of your group or by your teacher. They should be just a few seconds apart. Pull the tape slowly and switch the ticker timer on at the start signal. Switch it off at the stop signal.
8. Count the number of dot-to-dot spaces between the start and the stop. That is the time between the signals, measured in 'ticks'.
9. Use a fresh piece of tape, and a stopwatch or stopclock. Pull the tape through the ticker timer for 3 seconds. Find out how many 'ticks' there are in 3 seconds. Find out how many there are in 1 second. Work out the time in seconds that is the same as 1 tick.

Results

Once you have determined how many dots are made in 1 second (or 3 seconds), you can measure the time by dividing the number of dots by how many are made in 1 second.

Experiment 18.2

Aim: Calculating average acceleration using a ticker timer

Materials: a trolley, elastic cords for accelerating trolley, a rod for attaching elastic cord to trolley, a ticker timer with power supply unit, ticker tape, sticky tape

Procedure

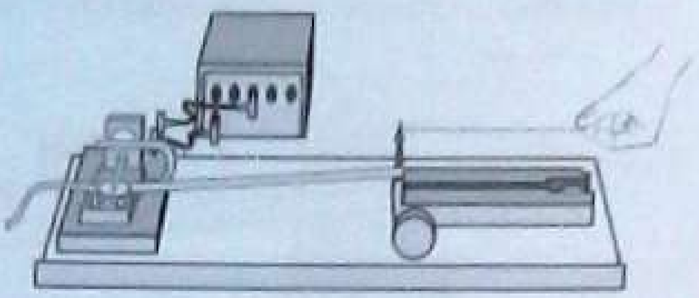
1. Thread a length of ticker tape through a ticker timer and attach the end to a trolley.
2. Pull a trolley with a fixed force along a bench. Loop one end of the elastic cord around a rod attached to the trolley. Keep the force constant by making sure that the cord is always stretched by the same amount as the trolley moves. Practice doing this.
3. Choose and cut through a dot near to the start of the tape. Do this when the trolley is travelling quite slowly but the dots are far enough apart to clearly distinguish one from another.
4. Count ten dot-to-dot spaces and cut the tape, through a dot, again. You have cut a 'ten-tick-tape'.
5. Count 40 more dot-to-dot spaces along the tape. Then cut the next 10 dot-to-dot spaces to make another ten-tick-tape.
6. Draw a horizontal line, as a time axis, on a piece of paper. Glue your tapes, vertically and 10 centimetres apart, so the bottom of each tape touches this axis. This 10 centimetres represents 1 second.
7. Draw a vertical axis anywhere to the left of the first tape. This is a velocity axis.
8. Mark a scale, in centimetres per second, on your vertical axis. Each vertical centimetre on your axis represents 5 centimetres per second.

9. Use your velocity axis to help you to work out the first velocity and the second velocity. You can call these u and v. (Remember that u comes before v in the alphabet, just as the first velocity comes before the second.)

Work out the average acceleration of your trolley during the time between the two tapes. Acceleration is 'rate of change of velocity'. It is equal to the change in velocity divided by the time. Average acceleration = change in velocity/time taken.

The change in velocity is the difference between the two velocities, $v - u$. The time between these two tapes is t, which in this case is 1 second.

10. Draw a straight line between the centres of the tops of the tapes. Draw a horizontal line from the centre of the top of the first tape. Draw a vertical line through the top of the second tape. You have made a right-angled triangle. The length of the base of your triangle, using the units of the horizontal axis, is 1 second.



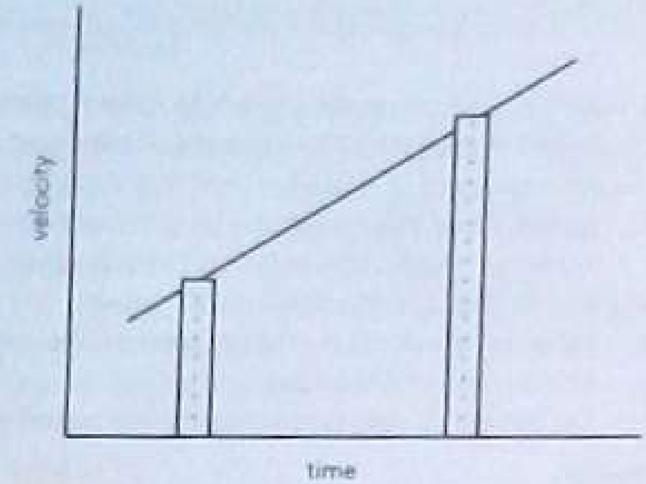


Figure 18.1 Using a ticker timer to calculate average acceleration

Results

Find the gradient of the line connecting the tops of the two tapes. Measure the height of the triangle, using the units of the velocity axis, which are centimetres per second (cm/s). Divide the height of the triangle, in centimetres per second, by the base, in seconds. This gives you the average acceleration in centimetres per second per second (cm/s²).

Experiment 18.3

Aim: To investigate the relationship between force and **acceleration**

Materials: a trolley, a runway, a few books, a ticker timer, ticker tape, elastic bands, an alternating current or direct current power source depending on the ticker timer

Procedure

1. Set up the apparatus as shown in Figure 18.2. Incline the runway so that the trolley just starts moving on its own. Then reduce the slope slightly and give the trolley a slight push. Adjust the slope until the trolley runs at the same speed down the runway when it is pushed.

The dots on the ticker tape will be equally spaced when the trolley is moving at constant speed. When this happens, we have compensated for friction and it will no longer have an effect on the experiment.

Remember, we have only compensated for friction, we have not eliminated it.

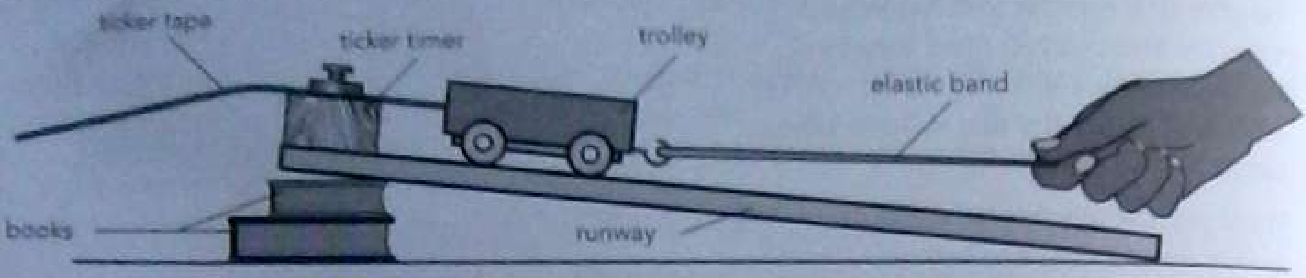


Figure 18.2 Investigating the relationship between force and acceleration

2. With the trolley at the top of the runway, turn on the power supply and pull the trolley with a constant force (F) by keeping the elastic band at the same length.
   You may need to practise to get this right.
3. Attach a new ticker tape and pull the trolley with two identical elastic bands that are stretched to the same length. This provides twice as much force ($2F$).
4. Repeat Step 3, using three elastic bands.
5. Make a ten-tick chart. The gradient of the line that joins the tops of the strips gives the acceleration of the trolley.
   Do this for all three experiments and record your results in a table.

Results

The results of this experiment show that the line joining the tops of the strips is a straight line. This shows that the constant force you applied produces a constant acceleration. You should also have noticed that the acceleration due to the force equal to $2F$ was twice that of force F. Likewise, the acceleration due to the force equal to $3F$ was three times greater than the initial force F.

This indicates that the acceleration (a) is directly proportional to the force (F).

In symbols: $a \propto F$

Experiment 18.4

Aim: To investigate the effect of mass on acceleration

Materials: a trolley, a runway, a few books, a ticker timer, ticker tape, elastic bands, an alternating current power source, two masses of 1 kg

Procedure

1. Use the same apparatus as in Experiment 18.3.
2. Compensate for friction as you did previously.
3. Pull the trolley down the slope using a constant force (F).
4. Use a fresh ticker tape. Place one 1-kg mass on the trolley and pull the trolley with the same force F you used in Step 3.
5. Use a fresh ticker tape. Place the second 1-kg mass on the trolley and pull the trolley with the constant force F.
6. Make a ten-tick chart and calculate the acceleration of the trolley. Record your results in a table.

Results

This activity shows that acceleration decreases as mass increases.

This means that the acceleration (a) is inversely proportional to mass (m). In symbols this gives us

$a \propto \frac{1}{m}$

Experiment 18.3 and Experiment 18.4 demonstrate the relationship between force, mass and acceleration. From these relationships comes Newton's second law:

The acceleration of an object is directly proportional to the force that causes it, provided that the mass remains constant.

We can summarise this relationship in a single equation:

$F = ma$

Examples

1. What is the force that acts on a 2-kg mass when a constant acceleration of 3 m/s² is experienced?
2. A constant force of 2 N is required to keep a 1.2-kg trolley moving at a constant speed along a horizontal runway. Find the acceleration of the trolley if a force of 5 N is applied to it.

Answers

1. $m = 2$ kg and $a = 3\ m/s^2$

   $F = ma$

   $= 2 \times 3$

   $= 6$ N

2. As 2 N is required to keep the trolley moving with constant velocity (the speed and direction are both constant). This means the motion of the trolley is opposed by a force of 2 N. This opposing force is equal to the friction acting on the trolley. Therefore, the resultant force on the trolley when 5 N is applied is (5 N – 2 N) = 3 N.

   $a = \frac{F}{m} = \frac{3}{1.2}\ m/s^2$

   $= \frac{3 \times 10}{1.2 \times 10}$

   $= \frac{30}{12}$

   $= 2.5\ m/s^2$

Newton's third law of motion

Newton's third law of motion states:

If a body (A) exerts a force on a second body (B), the second body (B) will exert an equal and opposite force on the first body (A).

Or, more simply:

For every action, there is an equal and opposite reaction.

This law is not strictly about *motion* as its name suggests, but the law tells us that forces always act in pairs. You will remember that we mentioned this at the beginning of this chapter. So, for example, a high jumper will exert an action on the ground. The reaction of the earth causes the jumper to spring upward, while the earth has hardly moved, because of its size.

Inertia

Newton's first law of motion states that an object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction, unless acted on by an unbalanced force. Objects tend to keep on doing what they are doing. It is the natural tendency of objects to resist change in their states of motion and it is called **inertia**.

Mass as a measure of an object's amount of inertia

All objects resist change in their state of motion; all objects have inertia. The tendency of an object to resist change in its state of motion depends on its mass. Mass is a quantity that is solely dependent on the inertia of an object. The more inertia an object has, the more mass it has, and a more massive object has a greater tendency to resist change in its state of motion.

If there are two bricks on a table, one brick made of cement and the other made of foam, without lifting the bricks, how can you tell which brick is made of foam?

You can use the same force to push each brick and change its state of motion. The brick that offers the least resistance is the brick with the least inertia, and therefore with the least mass, that is, the foam brick.

The mass of an object is always constant, no matter where the object is in the universe. It can be measured with a number of instruments, such as the beam balance in Figure 18.3.

Figure 18.3 A beam balance

What is weight?

The **weight** of an object is the amount of gravitational force that acts on the object. Weight is calculated by multiplying the mass of an object by the acceleration due to gravity:

weight = mass × gravity

Weight is a force, so that the SI unit for weight is the **newton** (N).

Once again imagine two bricks of the same size, one of foam and the other of concrete. The two bricks have the same volume, but the concrete brick has a much larger mass. Therefore, the earth's gravity will have a greater pull on the concrete brick, meaning it will have more weight than the foam brick.

Remember that weight *depends on* mass. They are not the same thing! Weight varies depending on where an object is in relation to the earth (or any other large body in the universe). Weight can be measured using a spring balances like the balances in Figure 18.4.

What is momentum?

Momentum can be defined as 'mass in motion.' All objects have mass. So, if an object is moving, it has momentum; there is mass in motion.

Momentum depends upon the variables mass and **velocity** (the speed at which the mass is moving in a given direction). The momentum of an object is equal to the mass of the object times the velocity of the object, that is:

momentum = mass × velocity

The symbol for the quantity momentum is the lower case *p*. Thus, the above equation can be rewritten as:

$p = m \times v$

where *m* is the mass and *v* is the velocity.

The equation illustrates that momentum is directly proportional to an object's mass and also directly proportional to the object's velocity.

Momentum is measured in the SI unit of kg.m/s (kilogram meter per second) or N.s (newton second).

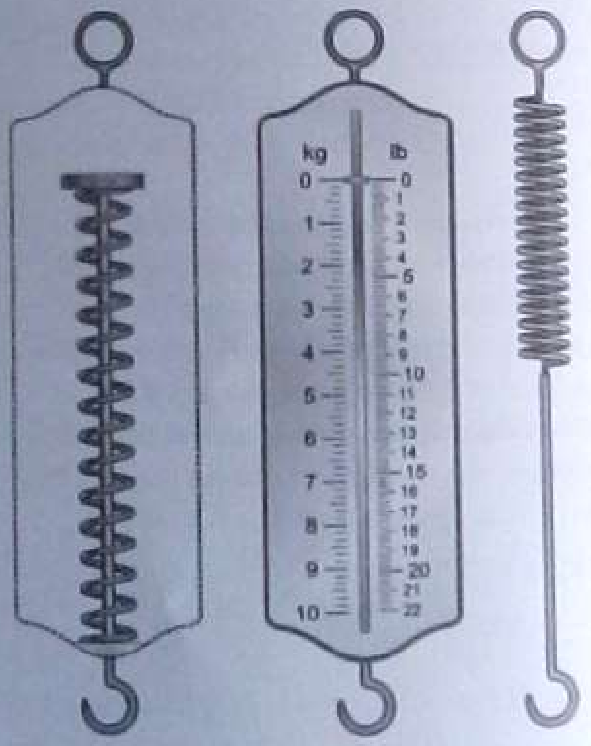


Figure 18.4 Spring balances or force meters. When graduated in, for example, grams and kilograms a spring balance can measure mass.

Summary

- **Newton's first law:** An object at rest or travelling at uniform velocity remains at rest or travelling at uniform velocity, unless a net force acts on it.
- **Newton's second law:** The net force acting on an object is equal to the rate of change of momentum. When the mass of an object is constant, $F = ma$.
- **Newton's third law:** Two interacting objects exert forces on each other that are of the same size, but opposite in direction.
- Mass is defined as a measure of the inertia of an object.
- Mass can be measured using a beam balance.
- Weight is defined by the formula $F = mg$.
- Weight can be measured using a spring balance.
- Momentum is the force exerted by a mass moving at a certain speed.
- The momentum of an object is its mass multiplied by its velocity.

Glossary

acceleration – change in the velocity of an object

force – a push or a pull tending to change an object's motion or state of rest, sometimes changing the object's shape

friction – the force that opposes motion between two surfaces moving past each other

inertia – the tendency of objects, dependent on their mass, to resist change in their state of motion

momentum – the force exerted by an object moving at a certain speed

velocity – the speed of a moving object in a given direction

weight – the force of an object due to the pull of gravity on its mass

Revision questions

1. State Newton's three laws. (6)
2. A 2 kg object is moving horizontally at a speed of 4 m/s.
   How much net force is required to keep the object moving at this speed and in this direction? (3)
3. Imagine that you are in a weightless environment. Would you need a force to set an object in motion? Motivate your answer. (2)
4. What instrument is used to measure weight? (1)
5. Explain the difference between mass and weight. (2)
6. An object with a mass of 10 kg is moving at a speed of 0,5 m/s.
   Calculate its momentum. (3)

TOTAL: 17

Unit 19 Machines

Objectives

- Identify some types of machines and describe their uses and applications.
- Calculate the mechanical advantage (MA), velocity ratio (VR) and efficiency of machines such as levers, inclined planes, pulleys and gears.
- Explain energy losses in machines.
- Describe ways of improving efficiency in machines.

Introduction

Machines are mechanical systems that are designed to make otherwise hard **work** easier. Examples of hard work include loading a drum of petrol onto a truck, opening a glass coke bottle with a metal cap and driving a screw into wood. Examples of machines that can make each of these jobs easier are illustrated in Figure 19.1.

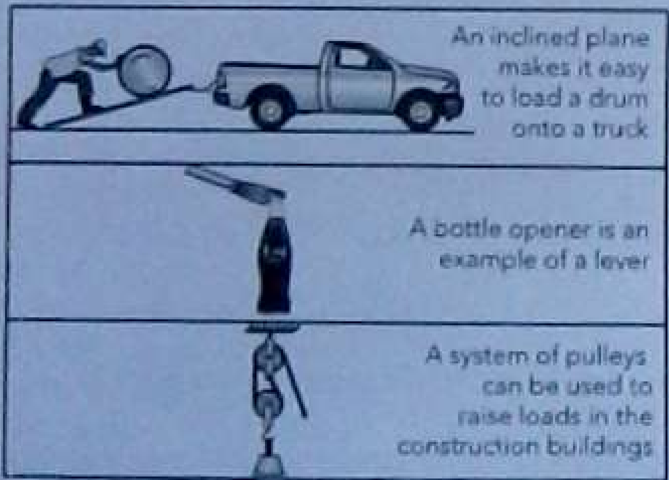


Figure 19.1 Examples of machines

Principles of machines

The following principles are very important in the functioning of machines: **mechanical advantage** (MA), **velocity ratio** (VR) and **efficiency**. Let us consider a **lever** used to move heavy loads. A lever has three important positions: the place where the lever turns is called the **pivot** (or fulcrum), the point where the **load** (L) is placed and the point where the **effort** (E) is exerted.

Mechanical advantage (MA)

Figure 19.2 illustrates a basic lever system. The starting position of the lever is AOB, where O is the pivot point. A boulder (the load) at point A has a weight W and you apply an effort E at point B. After your action, the lever has a new position, COD as shown. The load (at A) is x metres from the pivot (at O) and the effort (at B) is y meters from the pivot.

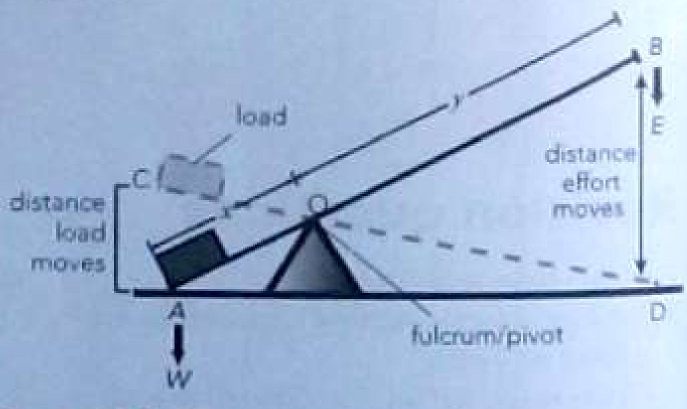


Figure 19.2 A lever raising a boulder

If the load is just raised, the mechanical advantage (MA) of the machine is the load divided by the effort:

$$\text{Mechanical advantage} = \frac{\text{load } (L)}{\text{effort } (E)}$$

Let us suppose the load with weight W was raised steadily through a height AC when the effort (E) was applied through a distance BD. The law of conservation of **energy** says that:

Work done by E = work done to raise W

or $E \times BD = W \times AC$

thus $\frac{W}{E} = \frac{BD}{AC} = \frac{y}{x}$ (use your knowledge of triangles to see how $\frac{BD}{AC} = \frac{y}{x}$)

Notice that the longer y is (and thus the shorter x is), the larger the ratio $\frac{y}{x}$ and thus the larger the mechanical advantage.

Efficiency

However, the actual amount of work done by the effort E does not all go into raising the load, but some of it goes towards overcoming friction. Work done against friction is wasted energy, or, the work done by E equals:

work done to raise L + wasted energy

Therefore, the more friction there is the more energy is wasted. The efficiency of a machine is defined as:

$$\text{Efficiency} = \frac{\text{work obtained from machine}}{\text{work put into machine}} \times 100\%$$

Since work obtained from a machine is always less than the work put into the machine, the efficiency of any machine is always less than a hundred per cent.

Velocity ratio (VR)

In Figure 19.2 above, the effort E moved through a distance BD over the same period of time that the load moved through a distance AC. The **velocity ratio** is defined as the relative distance moved by the effort over the simultaneous distance moved by the load, that is:

$$\text{Velocity ratio} = \frac{\text{distance moved by effort}}{\text{distance moved by load during the same time}}$$

From the geometry of Figure 19.2, equation 3 can be rewritten as:

$$VR = \frac{BD}{AC} = \frac{y}{x}$$

This last equation shows that velocity ratio depends on the distance from the fulcrum to the effort and from the fulcrum to the load. Velocity ratio therefore depends on the geometry of the moving parts. On the other hand mechanical advantage depends on friction between the moving parts.

How MA, VR and efficiency are related

We have seen above that efficiency is defined as:

$$\text{Efficiency} = \frac{\text{work obtained from machine}}{\text{work put into machine}} \times 100\%$$

But we know that:

work done = force × distance moved by the force

as it overcomes the load. The efficiency equation can therefore be rewritten as:

$$\text{Efficiency} = \frac{W}{E} \times \frac{AC}{BD} \times 100\%$$

But $\frac{AC}{BD} = \frac{x}{y}$

$$= \frac{L}{E} \times \frac{x}{y} \times 100\%$$

Now $\frac{L}{E} = MA$ and $\frac{y}{x} = VR$

Therefore $\text{Efficiency} = \frac{MA}{VR} \times 100\%$

Types of simple machines

Levers

Figure 19.3 shows examples of levers used in everyday life. For each lever, identify the pivot (or fulcrum), the point where the load is placed and the point where the effort is exerted.

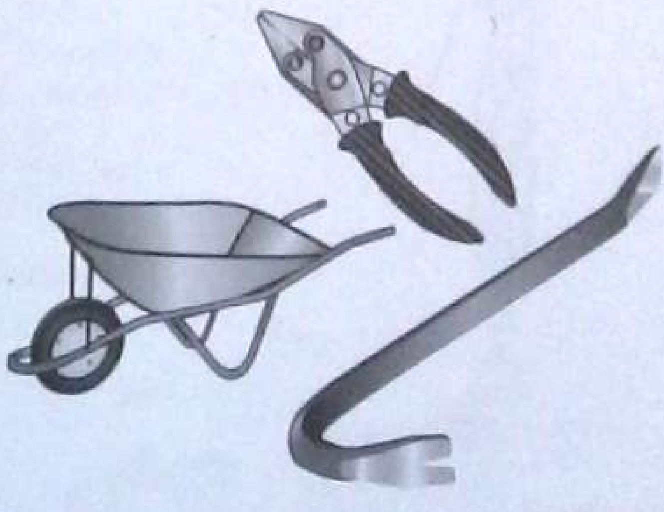


Figure 19.3 Levers used in everyday life

Pulleys

A **pulley** is a wheel with a groove through which a rope passes. Pulleys are used to lift loads, for example, in loading and offloading trucks and ships.

Examples of pulleys are shown in Figure 19.4. The advantage of using even just a single-pulley system is that, by pulling at one end, a person or a machine on the ground can raise the load. Builders use such pulleys to raise loads to higher floors of buildings.

Systems of two or more pulleys are much more useful machines, as they allow a smaller effort to raise a much heavier load than with a single-pulley system. Examples of such machines are cranes where many pulley wheels are threaded together. Cranes can lift very heavy loads such as cars, shipping containers, and so on.

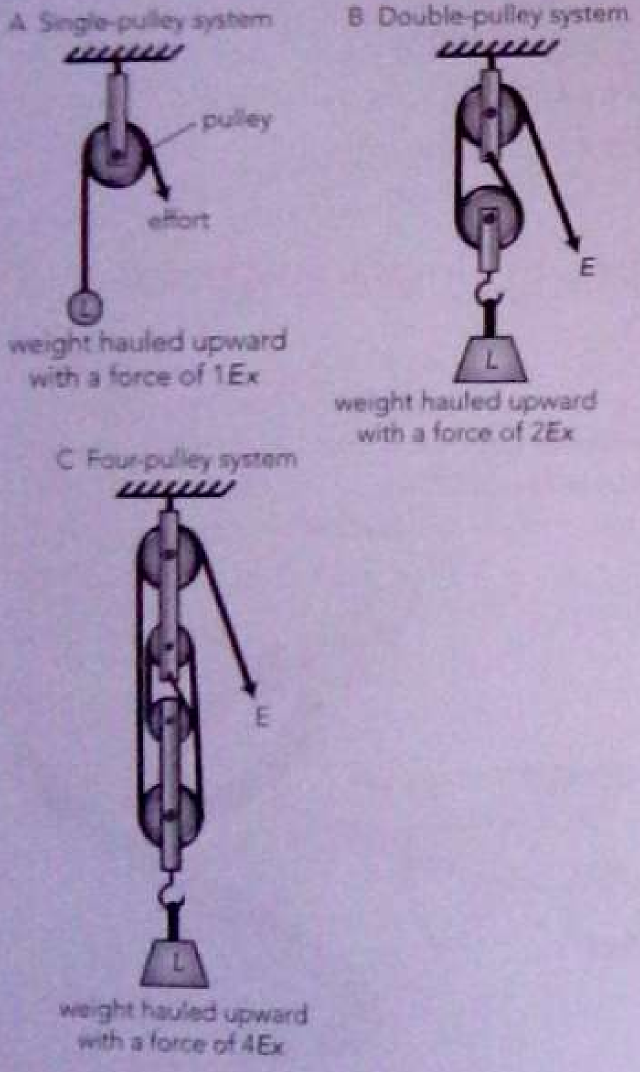


Figure 19.4 Some pulley systems

Advantage of using more than one pulley

Consider the two- and four-pulley systems shown in Figure 19.4. Suppose a 50 N effort is applied to pull the rope downward at point E. The tension everywhere along the rope is 50 N. Since there are two bits of rope on the lower pulley pulling upward, the load is being hauled with a force of $2 \times 50 \text{ N} = 100 \text{ N}$. The effort has therefore been doubled by the system. Similarly three- and four-pulley systems treble and quadruple the effort respectively. In real life, however, some of the force goes towards overcoming friction, so that more than 50 N would be required to raise a 100 N load on a two-pulley system.

Mechanical advantage of a pulley system

Suppose our real life four-pulley system requires an effort of 60 N to raise a 400 N load, then mechanical advantage is given by:

$$MA = \frac{L}{E} = \frac{400}{60} = 6.67$$

Velocity ratio of a pulley system

We want to know how far the effort has to move to raise the load a distance x. In Figure 19.4 C, the load moves a distance x if the two lower pulleys rise a distance x. For this to happen, each of the two lower pulleys has to release:

$$2 \times x \text{ rope} = 2x.$$

There are two more pulleys on the upper tackle also releasing a length x of rope each. Altogether $4x$ amount of rope is released.

Therefore E has to move by this amount and the velocity ratio (VR) is given by:

$$VR = \frac{\text{distance moved by } E}{\text{distance moved by } L} = \frac{4x}{x} = 4$$

In general, therefore, the velocity ratio equals the number of pulleys in the system.

Energy losses and efficiency of pulleys

In real life there is always friction between all moving parts of a machine. Work has to be done to counteract the force of friction. Part of the effort thus goes towards overcoming friction.

Friction cannot be eliminated completely, but it can be reduced. Applying oil or grease between all moving parts reduces energy loss through friction. The block of pulleys that is raised with the load is another source of energy loss. Energy loss can be reduced by using very light materials, such as aluminium, in making the lower block.

Activity 19.1

Aim: To measure the *MA*, *VR* and efficiency of a pulley system

To predict and test which of the two, the weight or the weight pan, will move more than the other

Materials: a 2-block pulley system, cordage of appropriate length and thickness, a variety of weights (masses), a 5-N weight, a scale-pan, a retort stand and clamp

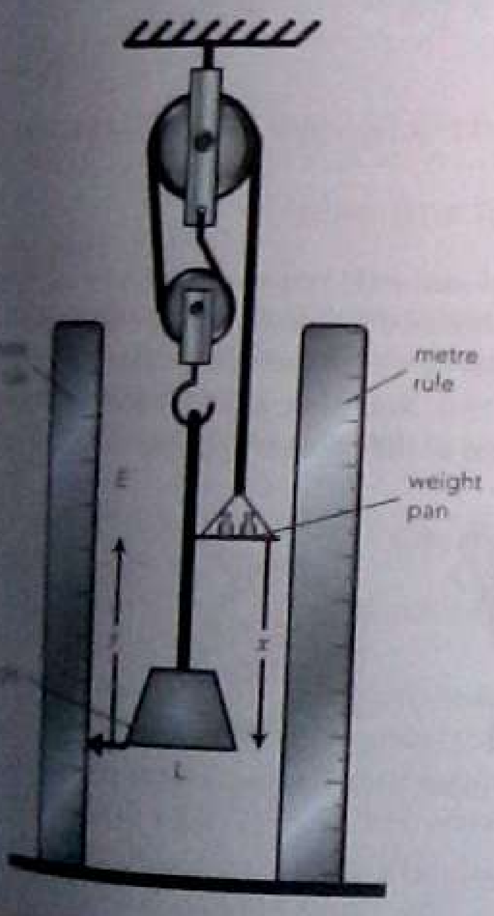


Figure 19.5 Loading a pulley system

Procedure

1. Hang the 5-N weight (*L*) as shown. Load known weights on the scale pan until the load begins to rise steadily.
   Record the load and the total effort (weight of scale pan + weights).
2. Pull the load to a convenient mark on the left rule.
   Record the position of the load and that of the effort.
3. Let the effort steadily move the load and then stop the system at another position.
   Record the new readings.

Results

Calculate mechanical advantage as follows:
Let us suppose the load is 5 N.
Effort = weight of scale pan + weights.
Let us suppose it is 1.2 N.
$MA = \frac{L}{E} = \frac{5}{1.2} = 4.2$
Calculate velocity ratio as follows:
Suppose the load moved through a distance y when effort moved through distance x, then:
$VR = \frac{y}{x}$
Calculate efficiency as follows:
Remember efficiency is:
work obtained divided by work supplied × 100%
Therefore:
Efficiency $= \frac{L \times y}{E \times x} \times 100\%$
or
$\frac{MA}{VR} \times 100\%$

Inclined plane

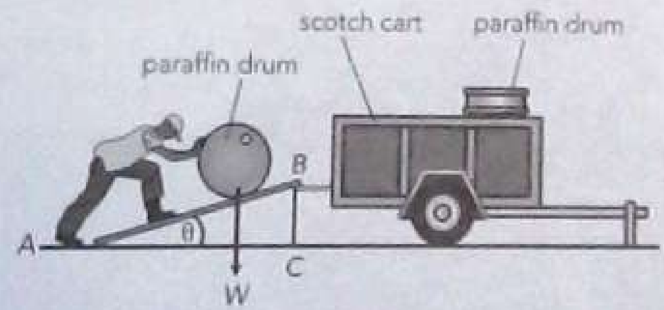


Figure 19.6 Using an inclined plane

In Figure 19.6, in order to raise the drum up from C to B, it is easier to roll the drum up the slope AB, than to lift it up directly. When the weight W is raised steadily when an effort E pushes the load up the distance AB, the load itself is raised a distance CB.

$$MA = \frac{L}{E}$$

$$\text{Efficiency} = \frac{L \times CB}{E \times AB} \times 100\%$$

$$VR = \frac{\text{distance moved by } E}{\text{distance moved by } L}$$

$$= \frac{AB}{CB} = \frac{1}{\sin \theta}$$

Note: $\sin \theta = \frac{CB}{AB}$ so that $\frac{1}{\sin \theta} = \frac{AB}{CB}$

Gears

A **gear** is a system of wheels with interlocking teeth so that one wheel drives another, as shown in Figure 19.7. The gear with 12 teeth shown makes two revolutions to drive and rotate another gear with 24 teeth full cycle, so that the velocity ratio of the machine is 2. Note that the small gear is the effort, while the large gear is the load.

In motor vehicles, when a small gear drives a larger gear, the vehicle is said to be in heavy or low gear. Low gears are engaged when the load is heavy, for example, when a vehicle starts moving from a position of rest or when the vehicle is moving up a steep incline. Examples of steep inclines where vehicles will be in low gear are Boterekwa in Shurugwi and Christmas Pass in Mutare. Low gears have a large velocity ratio.

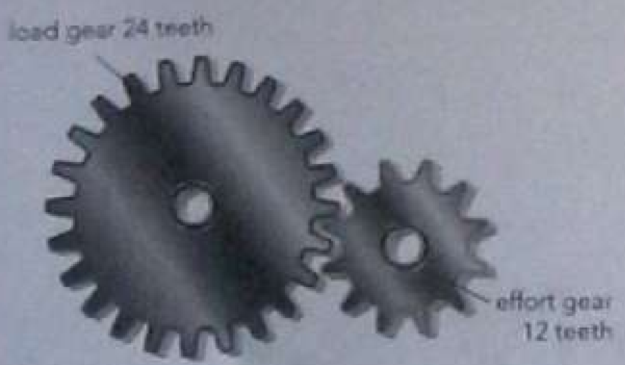


Figure 19.7 A low gear arrangement

The velocity ratio (VR) of the system is:

$$VR = \frac{\text{number of teeth on the driven (load) gear}}{\text{number of teeth on the driving (effort) gear}}$$

$$= \frac{24}{12}$$

$$= 2$$

High or light gears have a low velocity ratio and are used when the load is light. In motor vehicles, high gears are used when the driver wants the vehicle to move faster. For the top gear, the number of teeth on the load gear is the same as the number of teeth on the effort gear. This gives a velocity ratio of 1.

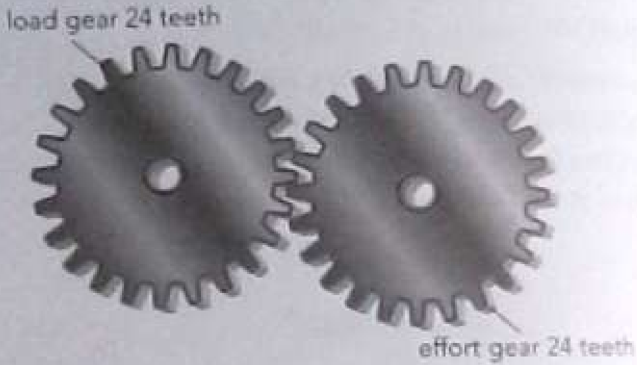


Figure 19.8 A high gear arrangement with $VR = 1$

Wheel and axle

A **wheel-and-axle** system comprises a big wheel that is attached to a smaller wheel that it turns. Examples of wheel-and-axle systems are shown in Figure 19.9. Note that, in all three examples, the direction of the effort is opposite to that of the load.

Figure 19.9 Some wheel-and-axle systems

When the effort turns the wheel (radius R) a distance of one circumference ($2\pi R$), the load (radius r) turns a distance = $2\pi r$, the circumference of the axle.

In this case the velocity ratio (VR) is found as shown below:

$$VR = \frac{\text{distance moved by effort}}{\text{distance moved by load}}$$
$$= \frac{2\pi R}{2\pi r}$$
$$= \frac{R}{r}$$

The mechanical advantage (MA) of a wheel and axle system is also $\frac{R}{r}$. This enables a small effort to be used to move a heavy load, for example, when a windlass on a well is used to draw water and when a car is turned.

Summary

1. Mechanical advantage (MA) of a machine $= \frac{\text{load } (L)}{\text{effort } (E)}$
2. Velocity ratio (VR) of a machine $= \frac{\text{distance moved by effort } (E)}{\text{distance moved by load } (L)}$
3. Efficiency $= \frac{\text{work obtained from machine}}{\text{work put into machine}} \times 100\%$
   or
   Efficiency $= \frac{MA}{VR} \times 100\%$
4. The mechanical advantage (MA) of a machine depends on the amount of friction present. The velocity ratio of a machine is independent of friction.
5. For a lever, the velocity ratio (VR) equals the ratio of the two arms, that is, $\frac{\text{pivot to effort}}{\text{pivot to load}}$.
   The mechanical advantage (MA) of a lever increases when the ratio of the arms increases.
6. For a pulley system, the velocity ratio (VR) equals the number of pulleys threaded together.
   Its mechanical advantage (MA) increases as the number of pulleys increases.
7. For an inclined plane, the velocity ratio (VR) is $\frac{1}{\sin Ø}$, where $Ø$ is the angle of inclination of the plane to the ground.
   Its mechanical advantage (MA) increases as $Ø$ decreases.

Glossary

efficiency – a measure of the ability of a machine to use energy given by the ratio of energy output to energy input

effort – the force applied to a machine to raise a load

energy – in mechanics, the ability to do mechanical work

gears – simple machines made up of interlocking wheels with cogs

inclined plane – a simple machine used to raise loads by making use of a sloping plane surface

lever – a simple machine used to lift or move loads by making use of a bar

load – the weight moved or lifted by a machine

machine – a device that makes work easier

mechanical advantage – the ratio of the load to the effort for a given machine

newton – the unit of force

pivot (fulcrum) – the support about which a lever turns

pulley – a simple machine made up of a wheel over which a rope passes and an axle

velocity ratio – the ratio of the distance moved by the effort to that moved by the load for a given machine

wheel and axle – a machine made up of a large wheel and a smaller wheel on the same axis, for example, a windlass

work – in mechanics, that which is done when a force moves an object with joule as the SI unit

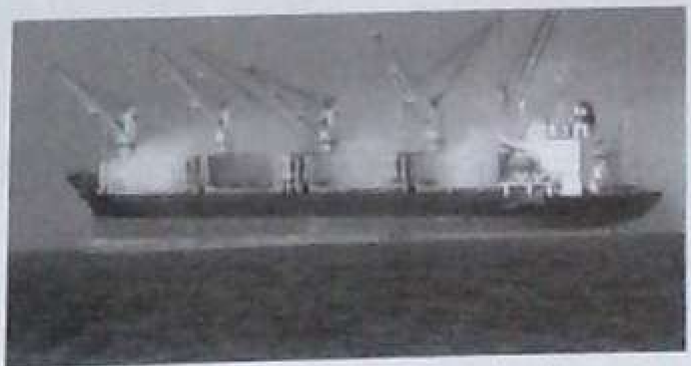


Figure 19.10 Cranes are sophisticated pulley systems.

Revision questions

1. Define mechanical advantage, velocity ratio and efficiency as applied to a simple machine. (6)
2. A lever system used to move a large rock is set up as follows:
   pivot to effort distance = 4 m
   pivot to load distance = 1.5 m
   weight of rock = 500 N
   a) What is the velocity ratio of the lever? (3)
   b) Calculate the effort needed to move the rock. (2)
   c) What is the mechanical advantage of the lever system? (2)
3. A pulley system has a velocity ratio of 4. If this system raises a load weighing 400 N when an effort of 150 N is applied, calculate:
   a) the efficiency of the system (3)
   b) the work done by the effort to raise the load by a vertical height of 4 m. (2)
   c) For the height in b) moved by the load, what distance did the effort have to move? (2)
4. With the help of a suitable diagram, describe how you would experimentally determine the velocity ratio of a two-pulley system. (10)
5. a) Draw a labelled diagram of a four-pulley system. (3)
   b) If, in testing the mechanical advantage of this system, the following results were obtained, answer the questions that follow:

Load (N)	20	80	140	220	300
Effort (N)	11	25	42	60	80

   i) Calculate the mechanical advantage of the machine in each case. (5)
   ii) Plot a graph showing how the mechanical advantage varies with the load. (5)
   iii) Give a reason why the mechanical advantage varies with the load. (2)

TOTAL: 45

Unit 20 Petrol and diesel engines

Objectives

- Describe the operation of a four-stroke petrol or diesel engine.
- Explain the role of the fuel injector and carburettor in engines.
- Outline the differences between petrol and diesel engines.

Introduction

When the first **internal combustion** engine was built in Germany in 1876, it revolutionised the world by allowing people to travel large distances in relatively short periods of time and by their not having to rely on animals like horses or oxen to pull large loads.

'Internal combustion' refers to the small explosions happening inside the engine that converts energy from the fuel source to kinetic energy.

Fuel sources

Internal combustion engines use petroleum or diesel, both of which are extracted from crude oil, as a fuel source to power its operations.

The operation of engines

Both petrol and diesel engines work by **internal combustion**, but in slightly different ways.

Both types of engines have a **fuel injection system** which transports fuel from the fuel tank to the engine and then delivers it into the system. This delivery is controlled by a fuel injector valve which limits the amount of fuel delivered into the system.

Fuel injection systems can either be direct or indirect. Direct systems spray the fuel directly into the cylinders where it combusts to power the engine. Indirect systems are first pumped into a **carburettor** before going on into the cylinders.

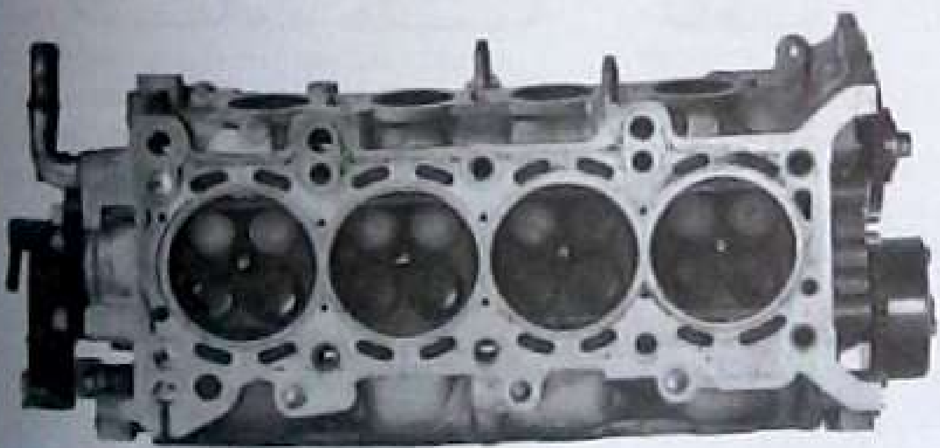


Figure 20.1 A photo of a cylinder head

Four-stroke petrol engine

Most modern cars have four-stroke petrol engines. The basic operation is as follows:

Stroke 1: **Intake.** The downward moving piston sucks a mixture of air and petrol vapour (gas) into the cylinder through the inlet valve. The exhaust valve is closed.

Stroke 2: **Compression.** The piston then moves upward, compressing the gas mixture. Both the inlet and the exhaust valve are closed.

Stroke 3: **Ignition.** Just before the piston reaches the top of the cylinder, a spark from the **spark-plug** explodes the gas mixture. The pressure caused by the quick expansion of the gas pushes the piston down, rotating a flywheel that is connected to the **crankshaft**. It is this rotation that is used to drive the wheels of the car. Both valves are closed.

Stroke 4: **Exhaust.** The piston moves upward again in the cylinder and pushes the gases out through the exhaust valve into the exhaust system of the vehicle. The inlet valve is closed and, as the piston moves down, it pulls more of the fuel and air mixture in to restart the cycle.

Exercise 20.1

Before turning to the diesel engine, answer the following questions about the four-stroke petrol engine.

1. Why does the fuel have to be mixed with air before it is sent into the engine?
2. What is the function of a spark-plug?
3. Draw an energy diagram to illustrate the conversion of energy from fossil fuel to movement of the car.

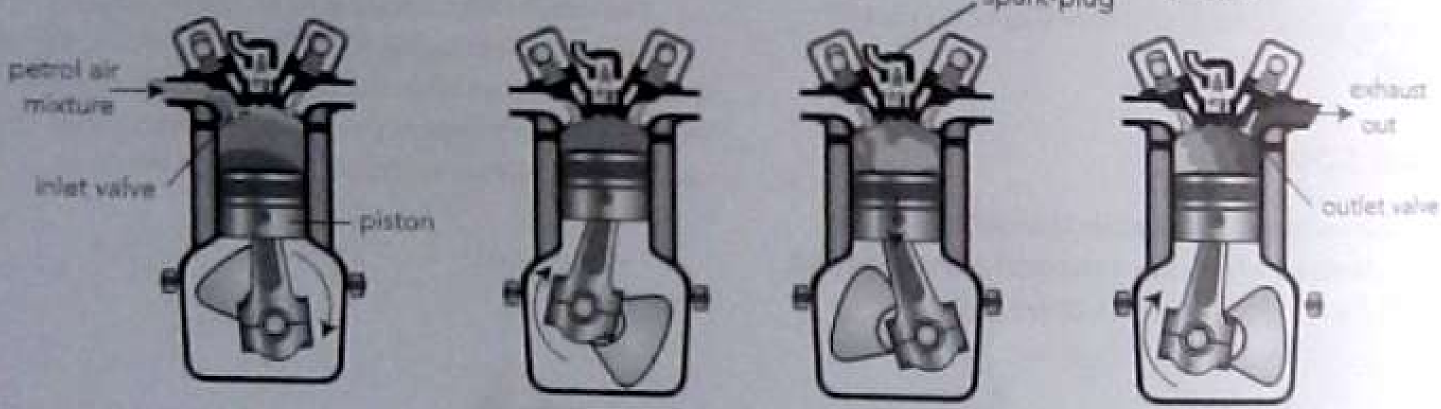


Figure 20.2 The functioning of a four-stroke petrol engine

The **fuel injection system** for a petrol engine is indirect, because it is first pumped through the **carburettor**, ensuring that petrol and air are mixed in the correct proportions, before letting it pass into the cylinders. Newer engines, however, have electronic direct fuel injection systems instead of carburettors and the fuel is delivered straight to the

Figure 20.3 An array of spark-plugs

Diesel engine

Diesel engines have a similar, but simpler, operation to that of petrol engines. The main difference lies in when the fuel is injected into the system.

Stroke 1: **Induction.** Air is drawn into the cylinder through the inlet valve.

Stroke 2: **Compression.** The piston moves upward, compressing the air so that it heats up.

Stroke 3: **Power or ignition.** Fuel is injected into the hot, compressed air through a central fuel injection valve, making it spontaneously ignite. As in the petrol engine, the pressure caused by the quick expansion of the gas pushes the piston down, rotating a flywheel that is connected to the crankshaft. As we have seen, this rotation drives the wheels of the car.

Stroke 4: **Exhaust.** The piston moves upward again in the cylinder and pushes out the gases through the exhaust valve into the exhaust system of the vehicle. As the piston moves down, it pulls more of the air mixture in to restart the cycle.

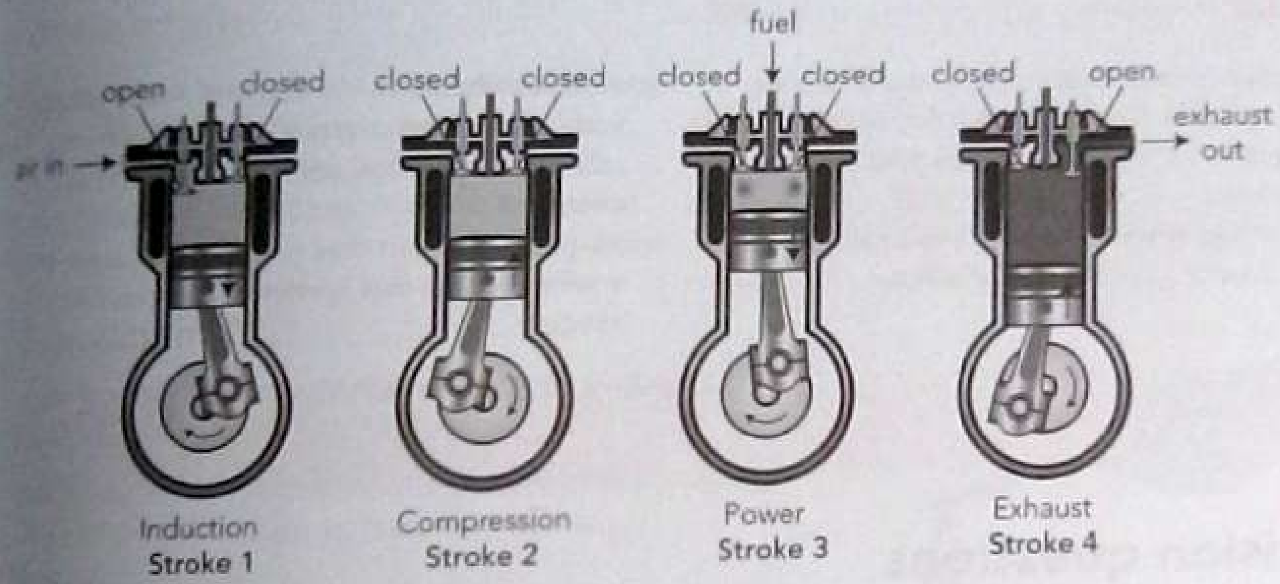


Figure 20.4 The working of a diesel engine

The fuel injection system for a diesel engine is direct, because it sprays the fuel directly into the cylinders. Because diesel engines have higher compression rates, that is, the air is compressed more in diesel engines than in petrol engines, they are more fuel efficient.

The function of a crankshaft

A crankshaft is driven by the pistons in the engine to transfer energy to the wheels. The crankshaft is the main rotating shaft running the length of the engine. The crankshaft is supported by main bearings. As the piston move up and down, the connecting rods move the crankshaft around. The turning motion of the crankshaft is transmitted to the transmission and eventually to the driving wheels.

Figure 20.5 A photo of a crankshaft with pistons

Summary

- Internal combustion engines convert chemical energy stored in fuel sources to mechanical energy.
- A fuel injection system transports fuel from the fuel tank to the engine.
- In petrol engines, a carburettor mixes fuel with air in a specific ratio, before injecting it into the cylinders.
- In diesel engines, fuel is injected directly into the cylinders.
- Internal combustion engines ignite a fuel and air mixture to push down a piston which turns a crankshaft connected to the wheels of the car.
- Diesel engines have a higher fuel efficiency than petrol engines.

Glossary

carburettor – the part of a petrol engine mixing fuel and air in the correct proportions

crankshaft – the part of an engine which drives the wheels

fuel injection system – direct or indirect system of introducing fuel into the cylinders

internal combustion – the process where an air and fuel mixture is ignited inside an engine, converting chemical energy to mechanical energy

spark-plug – the part that sends a small spark into a petrol engine that ignites the fuel and air mixture

Revision questions

1. What is the function of a carburettor? (2)
2. What energy conversion occurs in an engine? (3)
3. Describe the four-stroke action of a petrol engine. (4)
4. What is the difference between a direct and indirect fuel system? (2)
5. Why are diesel engines more fuel efficient than petrol engines? (2)
6. Name one similarity between petrol and diesel engines. (1)
7. What are the main differences between the intake strokes and the ignition strokes of petrol and diesel engines? (4)

TOTAL: 18

Unit 21 Energy and heat transfer

Objectives

- Give a molecular account of heat transfer.
- Explain convection in terms of the kinetic theory of matter.
- List good and poor reflectors, absorbers and emitters of heat.

Introduction

We know that a spoon left in a bowl of hot food will get hot after a while, even though most of it was not in contact with the hot food. This is due to the transfer of heat energy from the food to the spoon.

Heat transfer in solids

In this first experiment we will compare heat transfer in different solids.

Remember that heat can burn. Follow the procedure carefully so as not to get hurt.

Experiment 21.1

Aim: To investigate the rate of heat transfer in different materials

Materials: Bunsen burner (or other source of heat), rods of different materials (such as, iron, steel, carbon)

Procedure

1. Hold the different rods with one end in the Bunsen burner. Be careful not to get your hands too close to the flame.
2. Remove the rod the moment you can feel it getting warm.
3. Sort the materials in order of how quickly heat was transferred from the flame to the end of the rod.

Results

You should find that metals conduct heat better than non-metals.

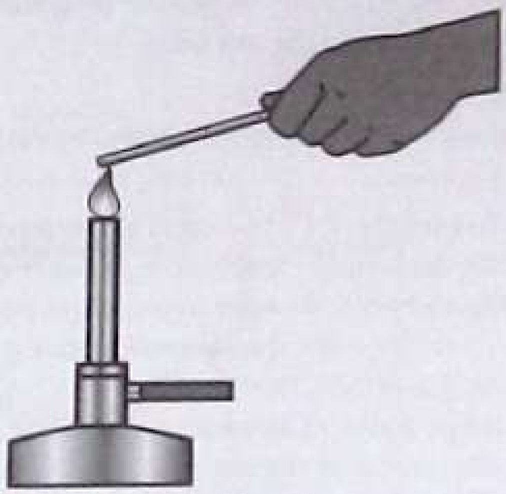


Figure 21.1 Good and poor conductors of heat

We know that the atoms in substances are always vibrating. When heat is applied to a substance, the heat energy is given to the atoms. This makes them vibrate and move faster, increasing their kinetic energy. The vibrating atoms bump into atoms that are close by and pass on their kinetic energy. This process is repeated throughout the substance. In this way, the heat energy moves through the substance.

Heat transfer from a region of higher temperature to a region of lower temperature, or **conduction**, is most effective in solids as their atoms are located closer together.

Metals are the best solids for conducting heat. Since metals are likely to give off electrons and their atoms are closely packed together there are more particles to bump into each other and they thus transfer heat faster.

We say that metals are good **conductors** of heat. Materials that do not allow heat to pass through them easily are called poor conductors of heat or **insulators**.

Heat transfer in liquids and gases

In this next section we will continue our investigation of how heat is transferred. We will start by looking at the ability of water to conduct heat.

Remember that heated water can be dangerous. Use the test tube holder and do not touch anything that was heated in a flame with your hands.

Experiment 21.2

Aim: To determine how well water conducts heat

Materials: a test tube, a test tube holder, a Bunsen burner, water, ice

Procedure

1. Put a small block of ice into the test tube and add water until it is about three-quarters full.
2. Heat the water at the top, as shown in Figure 21.2, until the water starts to boil.
3. Use your hand to feel the temperature at the bottom of the test tube.

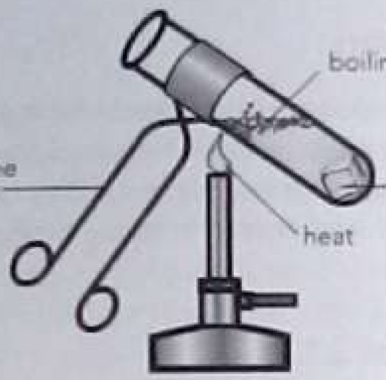


Figure 21.2 The conduction of heat in water

Results

Has much heat been conducted to the bottom of the test tube? Suggest two reasons for your answer.

In Experiment 21.2 the water at the top boiled, while the water at the bottom of the test tube remained cold. We were trying to get heat to move through the water by conduction, but it is obvious from this activity that heat does not conduct well through water. If, however, we heat the water at the bottom of the test tube, heat is quickly transferred throughout the liquid. The heat transfers from the bottom of the test tube by a method called **convection**.

Because hot **fluids** (liquids and gases) expand due to the increase in kinetic energy, they move upward. Since a **vacuum** is not natural, the colder liquid or gas rushes into the space left by the warmer liquid or gas.

Experiment 21.3

Aim: To demonstrate convection currents in water

Materials: a large glass beaker, a glass tube, potassium permanganate crystals, water, a tripod stand, a Bunsen burner

Procedure

1. Three-quarter fill the beaker with water.
2. Slide a few crystals of potassium permanganate down a glass tube so that they land in own place as shown in Figure 21.3. Block the top of the glass tube and remove it.

3. Place the beaker on a tripod stand and heat the beaker directly below the crystals, using a very small flame. Watch the water in the beaker carefully.

Results

Describe what you see happening as you continue heating the water. The purple streak that you see rising is actually warm water rising and following a path. The purple colour is just there to make this stream of water visible. To describe this stream of water we use the term **convection current**. The convection current keeps circulating through the water and distributing the heat until the water reaches boiling point.

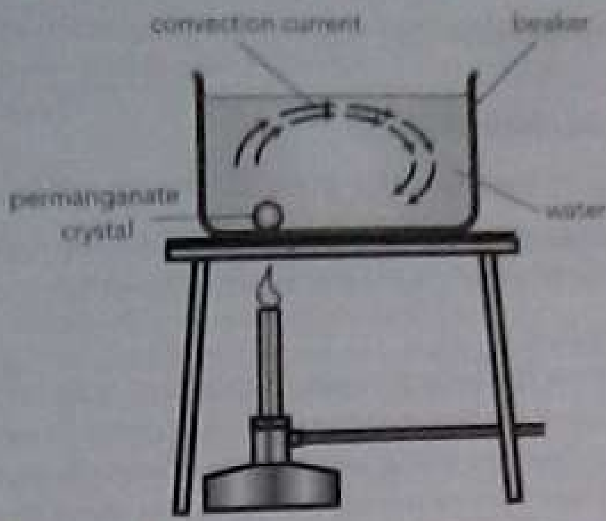


Figure 21.3 Convection currents in water

The conclusion to which we can come through the activity above is the following:

Heat moves (is distributed) in a liquid by convection currents.

Experiment 21.4

Aim: To demonstrate convection currents in gases

Materials: a box with two chimneys and a clear (glass or plastic) front, a candle, a rag or rolled paper

Procedure

1. Position a lit candle inside the box under the chimney to the left as shown in Figure 21.4.
2. Place the back of your hand just above the left chimney for one or two seconds.
3. Light the rag (or rolled paper) and let it burn a little before blowing out the flame. This leaves the rag smouldering and smoking.
4. Hold the smouldering rag just above the right chimney.
5. Watch the inside of the box through the clear front.

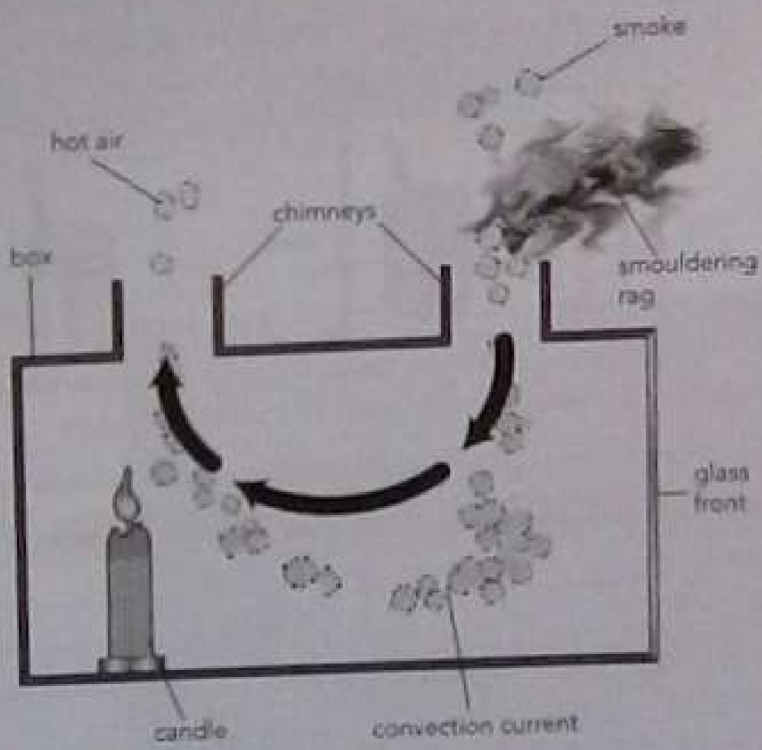


Figure 21.4 Convection currents in gases

Results

Describe the movement of the smoke.

The conclusion to which we can come through the above activity above is the following:

Heat moves through air (or gas) through convection.

Heat emission

Experiment 21.5

Aim: To investigate the effect of different surfaces on the rate heat is absorbed or emitted

Materials: two equal sized tins with lids (one painted black and the other a shiny metallic (reflective) colour or white), tap water, two thermometers

Procedure

1. Pour the same amount of water into both tins.
2. Close the tins and place a thermometer in each through a hole in the lid.
3. Record the initial temperature of water in each tin.
4. Place the tins outside in the sun for about 20 minutes.
5. Record the temperatures again.
6. Bring the tins back into the classroom and leave them for another 20 minutes. Now record the temperatures again.

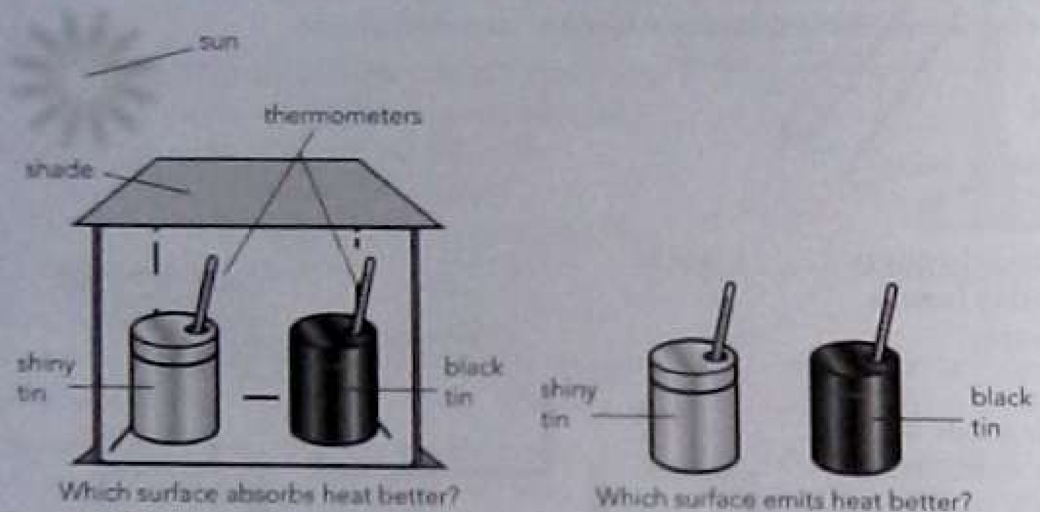


Figure 21.5 The absorption and emission of heat energy

7. Record your results in a table similar to the one shown below:

Time of measurement	Temperature of black tin	Temperature of other tin
At the start		
After 20 min		
After 40 min		

Results

Which tin absorbed heat faster?

Which tin emitted heat faster?

Discuss your answers with friends and ask your teacher to confirm or help you with conclusions. You may repeat the experiment to verify or rectify your conclusion.

Experiment 21.5 should have helped you come to the following two conclusions:

- Dark or dull surfaces absorb heat faster than shiny (reflective) or white surfaces.
- Dark or dull surfaces emit heat faster than shiny (reflective) or white surfaces.

Heat and transparent objects

Does heat **radiation** penetrate transparent objects like light does?

A house with a large window facing the sun gets very hot in summer. Cars also get very hot quickly when left in the sun with all windows closed. Greenhouses also get warm quickly when the sun rises. These examples show that heat is **transmitted** or moves through transparent objects such as glass and clear plastic.

Think of more examples and discuss them with your classmates.

Remember, radiant heat moves through space by wave motion and it travels at the same speed as light.

Some applications of heat emission

1. In hot climates people generally wear loose, white clothing. This keeps as much heat as possible away from the body.
2. Milk and petrol tankers are usually a shiny silver colour or painted white. This is to make sure very little heat enters the tanker, since fuel and milk must be kept as cool as possible.

Summary

- Heat moves from one place to another through conduction, convection or radiation.
- Conduction describes the movement of heat through solid materials.
- Materials that easily transmit heat energy through them are called conductors of heat.
- Those that do not conduct are called poor conductors or insulators.
- Heat energy moves through liquids and gases by convection.
- Different surfaces have different abilities to absorb and emit heat.
- Heat that is emitted moves through space by wave motion (it travels at the same speed as light).
- Heat is transmitted through transparent objects such as clear glass, plastic, and water.

Glossary

conduction – the transmission of heat energy through mostly solid materials

conductor – a thing or material allowing heat energy to pass through easily is a good conductor of heat

convection – the movement of heat energy through liquids and gases

emit – to send out, for example, heat

fluid – substance, especially a gas or a liquid, without a definite shape and able to flow

insulator – a material that does not allow heat energy to pass through it easily

radiation – method by which energy, such as heat energy, passes through a vacuum and space

reflection – the 'bouncing back' of energy, such as heat energy, when it hits a surface

transmit – allow to pass

vacuum – an empty space where no particles of matter are present

Figure 21.6 Heat energy from the Sun is transmitted through glass

Revision questions

Use the following list of words to complete the sentences below:

reflection — insulators — conduction — transmission — waves — convection — metals — radiation — conductors — vacuum — non-metals

1. _____ are materials that are poor conductors of heat. (1)
2. The bouncing back of heat energy when it hits a shiny surface is called _____. (1)
3. A space where there is absolutely nothing, not even air, is called a _____. (1)
4. The major method by which heat moves through liquids is called _____. (1)
5. The method by which heat moves through solids is called _____. (1)
6. The major method by which heat moves through gases is called _____. (1)
7. The major method by which heat moves through space is called _____. (1)
8. The passage of heat energy through transparent materials such as water and clear glass is called _____. (1)
9. Heat, like light energy, moves by means of _____. (1)
10. _____ are generally good conductors of heat while _____ are insulators. (2)

TOTAL: 11

Unit 22 Magnetism and electromagnetism

Objectives

- Describe how to demonstrate through an experiment that a conductor carrying an electric current has a magnetic field around it.
- Illustrate the motor effect, that is, how movement is produced when a wire carrying an electric current is placed in a magnetic field.
- Describe the operation of a direct current (DC) motor.
- Describe the generator effect, that is, how change in a magnetic field can induce an electromotive force (emf) in a conductor.
- List the factors affecting the magnitude of an induced electromotive force.
- Describe the operation of an alternating current (AC) and a direct current (DC) generator.

Introduction

The relationship between electricity and the force of magnetism is well known. The flow of electricity generates a small magnetic field around the wire through which it is flowing. Several factors can enhance the magnetic field thus produced.

Exploring magnetic field lines

Before we explore this further, let us first look at magnetic fields around bar magnets.

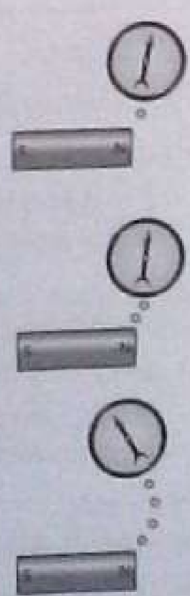
Experiment 22.1

Aim: To explore the pattern of magnetic field lines through two scientific methods

Materials: bar magnets, a plotting compass, unlined A4 paper, iron filings, a pencil

Method A: Procedure

1. Place a bar magnet in the middle of a sheet of paper and trace its outline with a pencil.
2. Place the plotting compass at the top of one end of the magnet. Put a dot on the edge of the compass in the northern direction as shown by the compass needle.
3. Move the compass in the direction of the needle, just after the first mark, and mark another dot. Repeat this until you have plotted the full path that is followed by the compass.
4. Remove the magnet and join the dots to see the shape of the field line. The direction of a field line is always away from the north pole and towards the south pole.



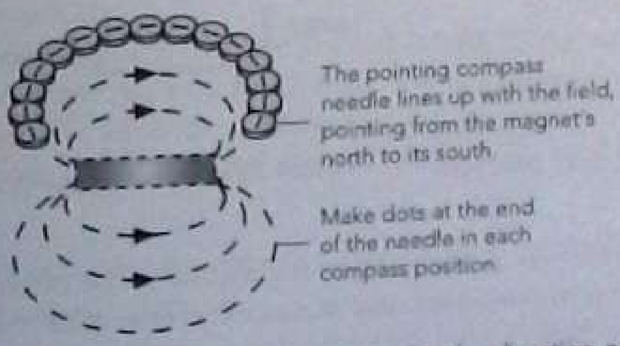


Figure 22.1 Using a compass to plot the direction of magnetic field lines

Method B: Procedure

1. Place the magnet under the centre of a piece of paper. Support the paper by placing two books at the shorter ends of the paper.
2. Sprinkle iron filings on top of the paper and tap the paper lightly. You should see a pattern emerge.
3. Plot the pattern with a pencil.
4. As in Method A, draw the direction of the magnetic field lines.

Figure 22.2 Using iron filings to show the shape of a magnetic field

The magnetic effect of an electric current

In this section we will perform experiments demonstrating the magnetic effect of an electric current.

Experiment 22.2

Aim: To show that a wire carrying an electric current generates a magnetic field

Materials: three 1.5-V cells, a switch, connecting wire, thin copper wire, iron filings, a 5-Ω resistor

Procedure

1. Connect the copper wire as shown in Figure 22.3.
2. Dip the copper wire into the iron filings. What happens?
3. Switch the current on and dip the copper wire into the iron filings again. What happens this time?
4. Turn the switch off. What happens to the iron filings on the copper wire?

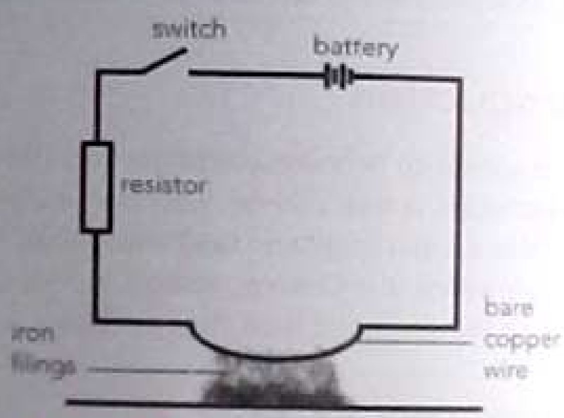


Figure 22.3 A wire carrying electric current acts as a magnet

Experiment 22.3

Aim: To demonstrate the magnetic field around a wire coil carrying an electric current

Materials: a long length of insulated copper wire, a 6-V cell or battery, a variable resistor, a 12 cm × 20 cm piece of cardboard, connecting wire, a small compass

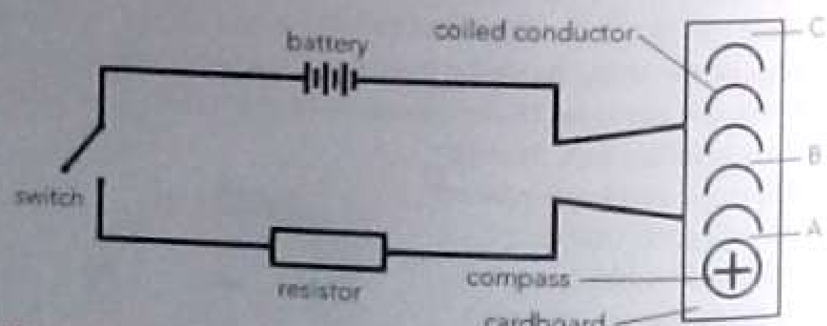


Figure 22.4 A coil carrying an electric current

Procedure

1. Draw two parallel lines, 5 cm apart, in the middle of the piece of cardboard.
2. Make holes along the two lines and thread the copper wire through the holes to form a coil as shown in Figure 22.4.

3. Set up the rest of the circuit as shown in Figure 22.4.
4. Set the variable resistor at about a third of its value.
5. Place the compass at one end of the coil and switch on the current. Note what happens to the compass.
6. Move the compass from position A to B and then to C. Note each time what happens.
7. Sprinkle some iron filings around the coil and tap gently on the cardboard. Watch what happens to the iron filings.
   You may have to reduce the resistance of the variable resistor somewhat to see better results.
8. Switch off the current.

From the two experiments above, it is clear that an electrical wire carrying current generates a magnetic field around it.

A coil carrying an electric current behaves like a bar magnet, with one end being the north pole and the other the south pole. A magnetic field is generated around the coil that becomes weaker the further away it is from the wire, just as if it were a bar magnet. In both cases, the wire only acts as a magnet as long as there is a current flowing through it. This type of magnetism is referred to as **electromagnetism**.

Applications of electromagnetism

We will now turn to some applications of electromagnetism.

The motor effect

A magnet will exert a force on a current-carrying wire. The next experiment uses a simple device to show that, when an electrical current flows through a magnetic field, a force is exerted on the current.

Experiment 22.4

Aim: To demonstrate that a conductor carrying an electric current experiences a force in a magnetic field

Materials: a powerful horseshoe magnet, electric wire,
a DC power supply, crocodile clips, a switch, a strip of aluminium foil

Procedure

Note: Do not close the switch for long as the circuit you are going to set up is a short-circuit. The large current that flows when you close the switch will deplete your battery very quickly.

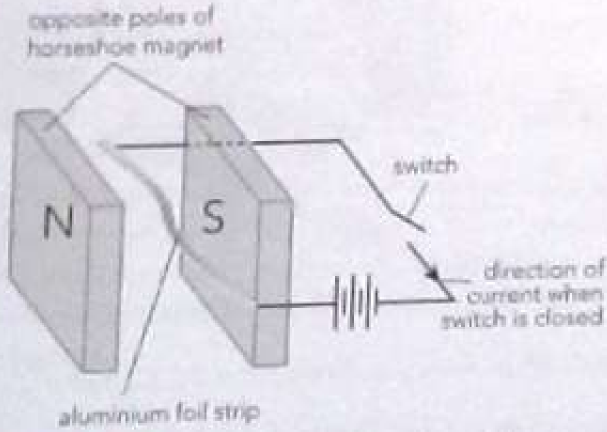


Figure 22.5 Exploring the direction of the force a magnetic field exerts on a current-carrying

1. Note: Do not close the switch for long as the circuit you are going to set up is a short-circuit. The large current that flows when you close the switch will deplete your battery very quickly.
2. Turn the switch on briefly and observe what the aluminium strip does. Does it move up or down?
3. Reverse the connections of the battery and note the direction the foil moves this time.

Results

The aluminium foil strip will move down when the current flows as shown in the diagram. When you reverse the connections of the battery, it will move up.

This force you have seen demonstrated in Experiment 22.4 can be used to make an electric motor. This is what we refer to as the **motor effect** of magnets.

The direct current (DC) motor

A wire that carries a current is kicked out of a magnetic field in a direction that depends on the direction of flow of current in the wire relative to the direction of the magnetic field. If a wire is bent into a rectangular shape and an electric current flows through it, it can be placed inside a magnetic field so that one side of the wire experiences an upward force, while the other side experiences a downward force. If the wire is pivoted properly and the current supplied is continuous, the wire will rotate. This is what happens in a simple direct current motor, which is shown in Figure 22.6.

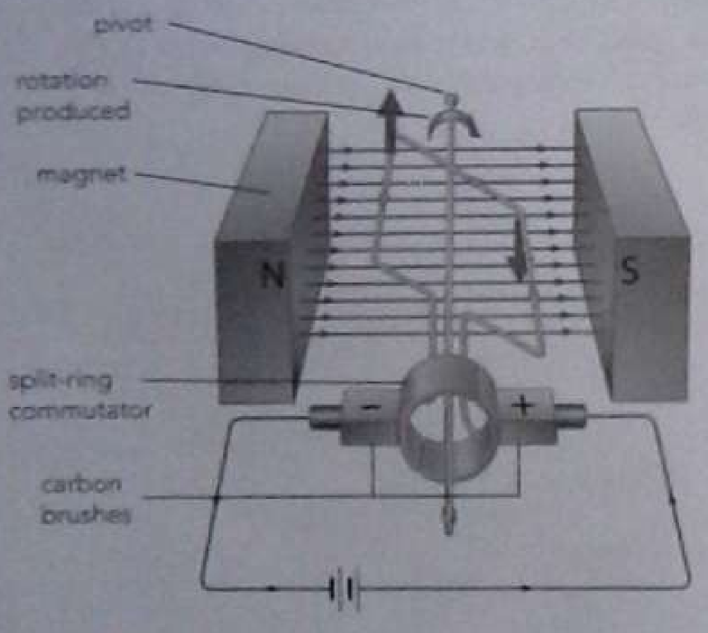


Figure 22.6 A simple direct current (DC) motor

The electric current enters the coil through the right brush of the **commutator**, and leaves through the left brush. As the commutator segments exchange brushes every half cycle, the current that flows through each side of the rectangular coil changes direction. This causes the rotating movement of the coil.

An **electric motor** changes electrical energy into mechanical energy.

The generator principle

The functioning of DC generators is based on the generator principle:

> *When a conductor is placed in a changing magnetic field, or when a conductor is moved in a magnetic field, an electromotive force (emf) is induced in the conductor.*

The **electromotive force** is a difference in electrical **potential** and gives rise to electrical current.

The direct current (DC) generator

Electric motors *use* electricity (electrical energy) to cause movement (mechanical energy), while electric **generators** *produce* electricity from movement.

A comparison of Figure 22.6 and Figure 22.7 shows that the direct current generator is almost identical to the direct current motor. The only difference is that the coil of the generator is made to rotate. The split ring causes an exchange of ring segments and brushes every time the coil is vertical. The overall effect is that the induced current always leaves the generator from one brush and enters through the other. Therefore, one brush stays positive and the other stays negative. The current in the external circuit therefore flows only in one direction; it is a direct current.

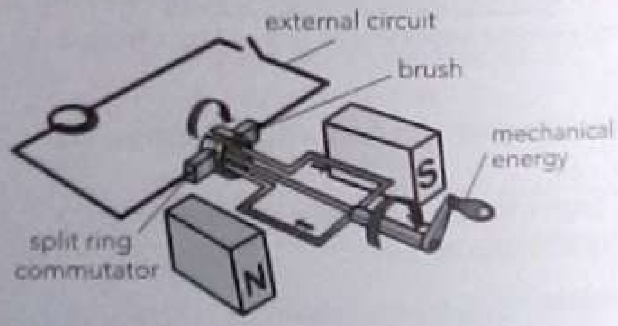


Figure 22.7 A direct current generator

The alternating current (AC) generator

A direct current generator will produce direct current, while an alternating current generator produces alternating current.

A simple change to the circuit shown in Figure 22.7 will change the type of current generated. For an AC generator, as shown in Figure 22.8, we use a slip ring commutator so that each side of the rectangular coil is always attached to the same brush. This means that the output current changes direction with every rotation of 180°.

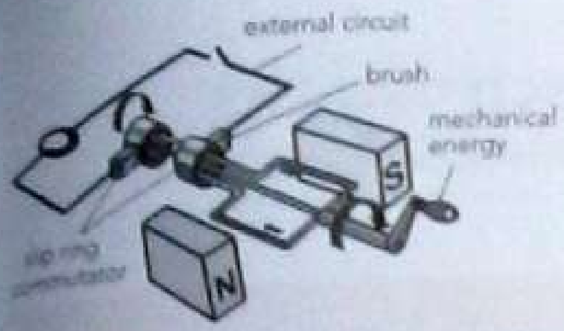


Figure 22.8 An alternating current generator

The magnitude of the electromotive force (emf)

The magnitude of the electromotive force (emf) can be increased by:

- using a stronger magnet
- increasing the relative speed of the movement
- increasing the number of coils
- increasing the area of the coil.

Summary

- A current-carrying conductor has an electric field around it.
- Lines of force, whether magnetic or electric, never cross.
- A current-carrying conductor in a magnetic field experiences a force. The direction of the force depends on the direction of the current and the direction of the magnetic field.
- A DC motor rotates when a current passes through it, due to the clash between the magnetic and electric fields.
- The magnitude of an induced potential difference (emf) depends on the relative speed of the conductor and the magnet, the strength of the magnet and the number of turns in the coil.
- An electric generator produces an electric current as a result of a conductor that rotates in a magnetic field.
- An electric motor converts electrical energy to mechanical energy and an electric generator converts mechanical energy to electrical energy.

Glossary

alternating current (AC) – an electric current changing direction of flow at regular intervals, for example, electricity supplied to homes

commutator – a device used to alternate electric current

direct current (DC) – an electric current flowing in one direction only, for example, a circuit with a cell

electric generator – device producing electrical energy from mechanical energy

electric motor – device producing mechanical energy from electrical energy

electrical potential – the potential to produce a flow of electricity

electromagnetism – magnetic forces produced by the flow of an electric current

electromotive force (emf) – a difference in electrical potential and gives rise to electrical current

Revision questions

1. Explain why a conductor carrying current experiences a force inside a magnetic field. (2)
2. Name the factors that influence the magnitude of an induced emf. (4)
3. Use a diagram to explain how a DC motor manages to keep turning in the same direction. (8)
4. List three ways in which the speed of a motor can be increased. (3)
5. Describe the similarities and differences between a direct current motor and a direct current generator. (3)

TOTAL: 20

Unit 23 Electricity and electrostatics

Objectives

- Describe how to demonstrate the presence of electrostatic charges by using an electroscope.
- Describe forces between charges.
- Describe the production of lightning.
- Explain the principle of a lightning conductor.
- List the dangers of lightning.

Introduction

Lightning is a spectacular result of **static electricity**. When thunderclouds **discharge**, we see bolts of lightning. You can probably remember occasions when you experienced a small electric shock on touching a metal door handle or the awkwardness when nylon clothes kept sticking to your body. Electrostatic forces, the subject of this unit, cause these experiences.

Figure 23.1 Lightning is the result of electrostatic charges in clouds.

Static electricity activities

The following three activities explore static electricity. You will need:

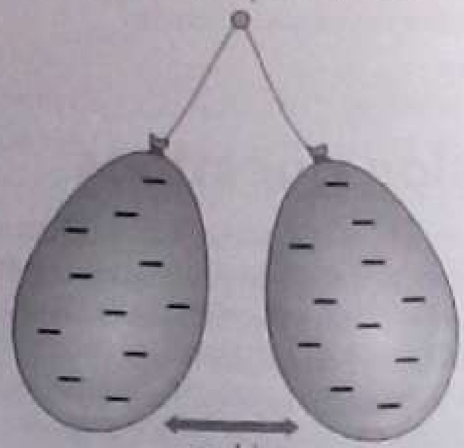
- a woollen cloth or jersey
- balloons
- a plastic comb and a tap
- string.

Activity 23.1

Blow up 2 balloons and tie each one closed. Tie a long thread or string onto the end of each balloon. Give each balloon a static charge by rubbing it with wool. Hold each balloon by the end of the thread and try to bring the balloons close to each other. What happens?

Results

Because the two balloons have like charges on their surface, they will repel each other.

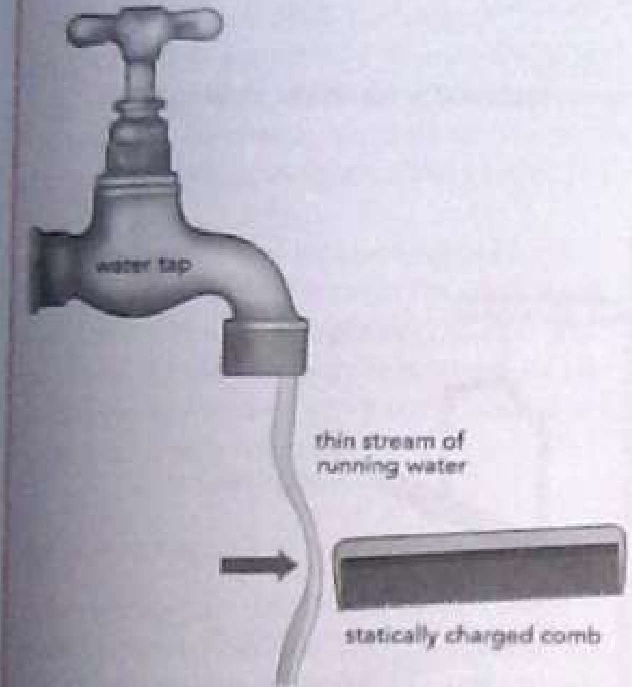


Activity 23.2

Rub a plastic comb with wool. Open a tap so a thin, steady stream of water comes out. Bring the comb near the stream of water. What happens?

Results

The stream of water is attracted to the comb.



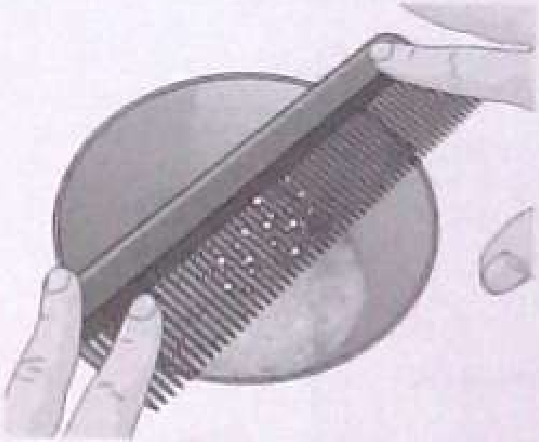
Activity 23.3

Sprinkle some salt on a plate or tabletop. Bring a charged comb near the salt.

Repeat the activity, this time with a mixture of salt and pepper on the tabletop or plate. Bring a charged comb near the mixture. What is different this time?

Results

The charged particles in salt are attracted by the charged comb. Pepper does not show any reaction at all.



Charges inside an atom

As you have learnt, all atoms contain particles that are called protons, neutrons and electrons. Protons are inside the nucleus of an atom and they carry a relative charge of +1. There are also neutrons in the nucleus, but they have no charge. The electrons travel around the nucleus in orbits. They carry a relative charge of −1.

Usually, the number of protons in the nucleus is the same as the number of electrons that orbit the nucleus. Therefore, an atom does not have an overall charge. If an atom gains electrons, it becomes negatively charged. If an atom loses electrons, it becomes positively charged. An atom that becomes charged by gaining or losing electrons is called an ion.

Charging materials by friction

Electrical **insulators** are materials that do not allow electricity to flow through them easily. However, if insulating materials are rubbed, they can be given an electric charge. For example, if an uncharged plastic rod is rubbed with an uncharged cloth, both objects can become charged. As you rub the rod, electrons from its atoms may move into the cloth. The rod will then be short of electrons and it will be positively charged. The cloth, on the other hand, will have an excess of electrons and will be negatively charged. Materials have different tendencies to gain or lose electrons through friction. Studying these tendencies is an important part of **electrostatics** and we call charges generated by friction **triboelectricity**.

Experiment 23.1

Aim: To demonstrate the behaviour of like and unlike charges when brought together

Materials: two polythene rods, one glass or Perspex rod, thread, two copper stirrups, a retort stand and clamp, a piece of fur, a piece of silk

Procedure

1. Set up the experiment as shown in Figure 23.2. Charge the polythene rod by rubbing it with fur. Place the charged rod on a stirrup suspended by thread. Charge a second polythene rod in the same way and bring it towards the suspended rod.
   Record what happens.
2. Charge a glass rod by rubbing it with silk. Now bring the glass rod towards the suspended polythene rod.
   Record what happens.

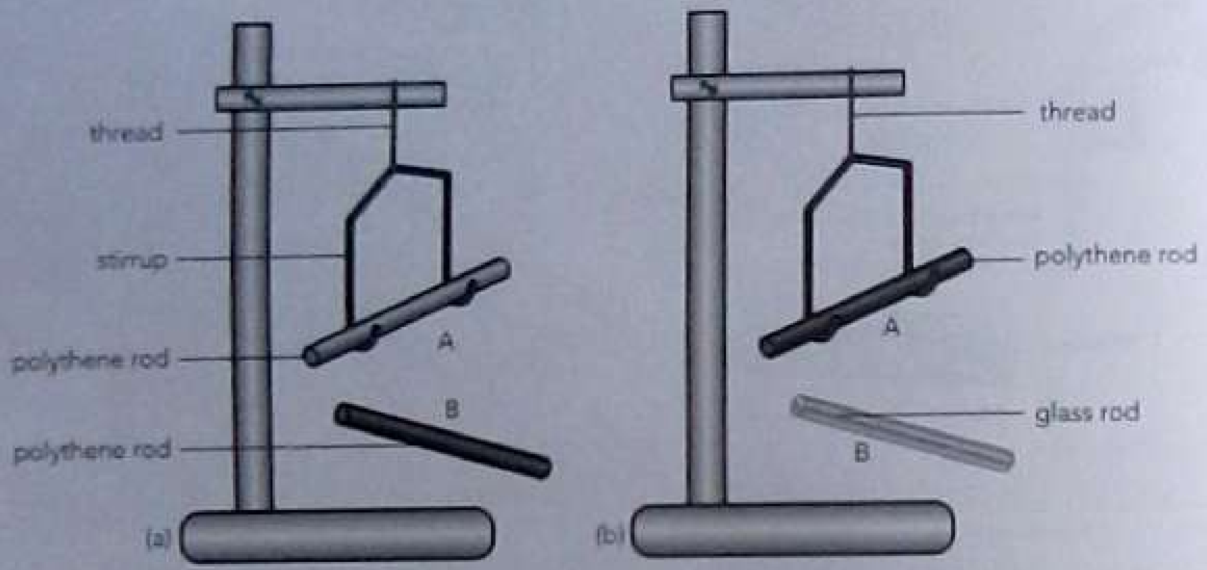


Figure 23.2 The forces of repulsion and attraction between like and unlike charges

Questions

Consider the following questions to explore your results.

1. If two rods of the same material are charged in the same way, what charge will they have? What is the effect of these charges on each other?
2. What charge will a glass rod have when charged, compared to the charge of the polythene rod? Do the rods have to touch for you to notice the effect?

In Experiment 23.1 rubbing polythene with fur transfers electrons onto the rod and it becomes negatively charged. Rubbing glass with silk removes electrons from the glass and it becomes positively charged. Using this information and the results of the exercise, we can conclude the following:

- Like charges repel each other.
- Unlike charges attract each other.
- Charges exert forces at a distance (the suspended rod was attracted or repelled without being touched by the other rod).
- The field that is created by an electrostatic charge is similar to a magnetic field (see Figure 23.3).

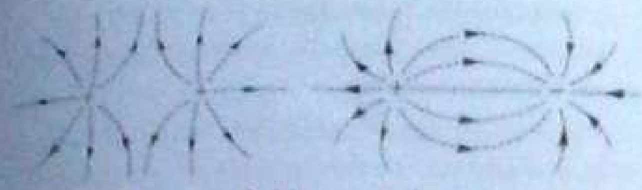


Figure 23.3 Electric fields are similar to magnetic fields

The coulomb

An electron carries a small quantity of negative electric charge (1.6×10^{-19} C). You would need a total of 6.25×10^{18} electrons to produce one **coulomb** (1 C) of charge. The proton carries the same value of charge as an electron, except that it is positive.

When two charges are close together, they have electrical potential energy. The **electrical potential** at a point is the potential energy per unit charge (in the same way that an object has potential energy because of its position relative to objects with which it interacts).

The electroscope

An **electroscope** is a device that detects **static electricity** through its thin metal (or plastic) leaves that will separate due to the presence of a charge.

Figure 23.5 A laboratory electroscope is calibrated to measure charges.

Suppose an object with a suspected static electric charge is brought near the metal plate or ball of an electroscope. If the object has a negative charge, electrons in the electroscope plate (or ball) will be repelled down the metal rod and to the metal leaves. Since each leaf will have a negative charge, they will repel each other and open out. Laboratory electroscopes do not only detect the charge but also the magnitude of the charge.

Activity 23.4

Aim: To make a simple electroscope

Materials: a clear glass jar, a lid for the jar or a piece of plastic that can cover the jar opening, electrical tape, 14-g or thicker copper wire, a straw, scissors, a glue gun, aluminium foil, fur, a balloon, a Perspex ruler

Procedure

1. Cut a 5-cm long piece of straw.
2. Make a hole big enough for the straw to pass through in the middle of the jar lid or plastic that will cover the jar opening.
3. Insert the straw in the hole and glue it securely with the hot glue gun.
4. Cut a 25-cm length of copper wire.
5. Twist the top 10 cm of the copper wire into a circle or spiral to create some surface area.
6. Insert the straight end of the wire through the straw to create a hook about 2 cm long.
7. Hang two small pieces of aluminium foil on the hook so that they make contact.
8. Place the hooked end of the metal into the jar and twist on or tape the lid to the jar.
9. Rub the balloon vigorously on your hair or with the piece of fur and bring the balloon close to the coiled wire on your electroscope.
10. Replace the balloon in Step 9 with the ruler.

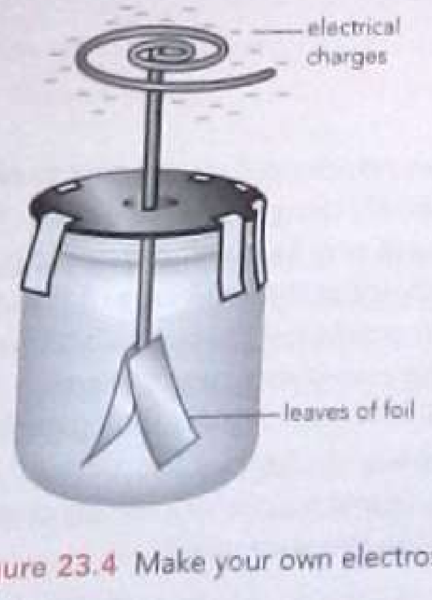


Figure 23.4 Make your own electroscope

Results

Bringing charged objects close to the coil should make the foil strips move apart.

Lightning

You have learnt that materials charge by friction. The same happens within storm clouds. The rapid movement of air and small frozen water droplets in a thundercloud causes the frozen water droplets to become charged. The smaller droplets charge positive and rise to the top of the cloud while the larger droplets charge negative and occupy the bottom of the cloud.

As violent movement in the cloud continues, the charging also continues. At the same time very high voltages (up to a million volts) build up between the positive and negative charges within the cloud. The negative charges at the bottom of the thundercloud repel electrons at the surface of the ground, pushing them deeper into the ground. The surface of the ground becomes positively charged.

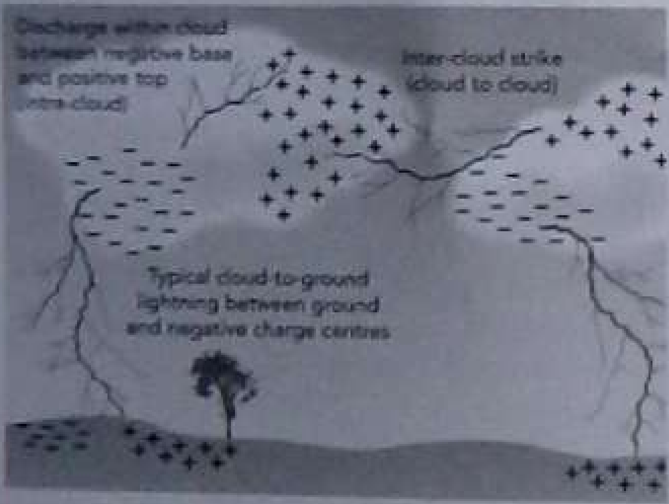


Figure 23.6 Electric fields between the clouds and the ground

Figure 23.6 shows two charged clouds next to each other and a positively charged ground surface. The intense charges and very high voltages created result in a breakdown of the insulation of the air. Charges are then conducted through this broken down air and this causes very large flows of current (up to 30 000 A). There are three possible conduction pathways in Figure 23.6, namely:

- conduction between positive and negative charges within the same cloud
- conduction between the two clouds shown
- conduction between the bottom of the clouds and the ground.

It is these large currents that heat up air to become white hot and we see this as bolts of lightning. The hot air expands rapidly sending shock waves which we hear as thunder.

Lightning safety and lightning conductors

The most dangerous place to be during an electric storm is outside. If a storm is approaching, try to go into a building with metal (such as metal pipes or gutters) connected to the ground. A building that does not contain metal (such as a thatch hut) is not safe.

Once you are inside a building:

- Move away from doors, windows and electrical appliances.
- Unplug computers, television sets, radios and appliances before the storm reaches you not when a storm has reached your area.
- Do not touch any plumbing (including sinks, baths and taps).
- Do not use a landline telephone. Current can travel large distances along telephone cables.

If you cannot get to a suitable building, try to get into a car and close the windows. Be careful and do not touch the metal or electrical parts of the car.

If you have to stay outside, follow these precautions:

- Squat down low with your feet together to reduce the potential difference between your feet if the current travels through the ground. Do not lie down or touch the ground with your hands.
- Move as far away as possible from water sources (such as rivers, dams or streams).
- Stay away from single trees and other tall objects (such as telephone poles).
- Stay away from high ground (such as the top of a hill).

- Do not touch anything that is made of metal (such as a fence or a bicycle).
- Make sure there is at least five metres between you and other people.

Lightning always strikes the tallest structures that conduct well, so that it can find its way to the ground. This is why tall buildings are fitted with **lightning conductors**. A **lightning conductor** or lighting rod is a metal rod with a sharp point. To be effective, conducting wires must connect a conductor to a metal rod in the ground so that, if lightning strikes the building, the charges will flow through the conductor and safely into the ground. In urban areas, electricity poles and telecommunication towers act as lightning conductors.

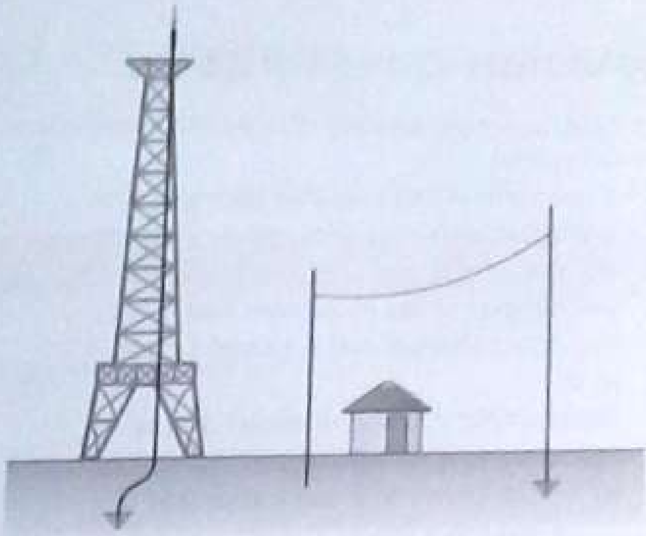


Figure 23.7 Lightning conductors

Summary

- There are two types of electric charge: positive and negative.
- Matter becomes negatively charged when electrons are added and positively charged when electrons are removed.
- Rubbing insulators with fur or silk makes them become positively or negatively charged.
- An electroscope is used to detect and measure small amounts of static electricity.
- Like charges repel each other, while unlike charges attract each other.
- Charges exert a force at a distance.
- A spark can jump between two materials of opposite charges if their voltage is large enough.
- Lightning is caused by the discharge of electrons between a thundercloud (which is negatively charged) and the ground (which is positively charged).
- Lightning conductors help us achieve lightning safety through the principle that lightning usually strikes the highest points.

Glossary

coulomb – the SI unit for measuring electric charge (positive or negative), equalling the charge of 6.25×10^{18} electrons

discharge – the release of electric charges from an object or the flow of electricity through air or another gas

electroscope – device used to detect static electricity

electrostatics – the study of static electric charges

insulator – in the context of electricity, it is a material that does not conduct electricity easily

lightning conductor – a tall piece of metal used to conduct lightning into the Earth away from buildings

static electricity – an unequal distribution of charges in an object, which may result in electrical discharge

triboelectricity – electric charges generated by friction

Revision questions

1. Explain how bodies are charged with static electricity. (2)
2. A polystyrene ball is coated with graphite and suspended near a negatively charged rod so that it is free to move. Explain what will happen to the suspended ball if the negatively charged rod is brought close to it. (2)
3. Explain why you should never do the following in a thunderstorm:
   a) Wash plates in a metal sink that is joined to a tap (1)
   b) Stand on a mountain top (1)
   c) Lean against a metal fence (1)
   d) Shelter under a tall tree (1)
4. Why it is safe to do the following during a thunderstorm?
   a) Stay inside a building that is protected with a lightning conductor (1)
   b) Stay inside a car (1)

TOTAL: 10

Unit 24 Ohm's law and resistors

Objectives

- State Ohm's law.
- Calculate resistance, voltage and current by making use of Ohm's law.
- Describe how you can determine resistance.
- State the limitations of Ohm's law.

Introduction

Any electrical circuit connected to a source of electrical power should have some form of resistance. Without it, a short-circuit with a very large flow of current can heat up wires and start an electrical fire. The relationship between current, potential difference and resistance will be outlined in this chapter.

Resistance

When applying a fixed potential difference across different components in a circuit, different values of current flow. This happens because the different components resist the flow of electrons by different amounts. Copper and aluminium offer very little resistance to the flow of electric current and they are relatively inexpensive. This is why these two metals are often used as electrical conductors. Figure 24.1 shows a few resistors. If a resistor has a potential difference (V) across it that is driving a current (I) through it, the resistance (R) of the resistor is defined by the following ratio:

$$R = \frac{V}{I}$$

Resistance is measured in ohms (Ω).

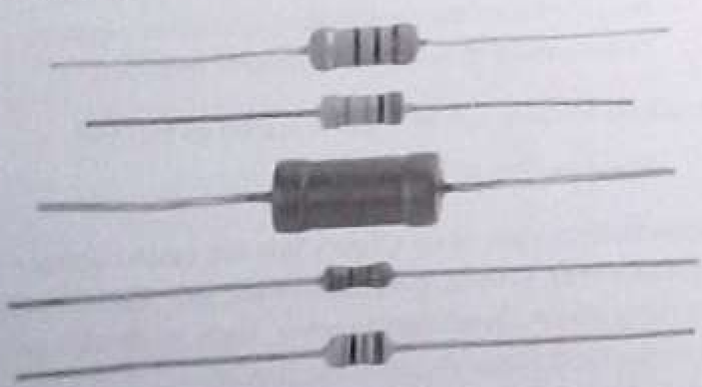


Figure 24.1 Different laboratory resistors

Experiment 24.1

Aim: To measure resistance

Materials: three torch cells, a rheostat, some nichrome wire, a voltmeter, an ammeter, some conductors

Procedure

1. Connect a circuit as shown in Figure 24.2. Your teacher will show you how to connect the rheostat.
2. Starting with the rheostat at its minimum resistance, close the switch and record the voltmeter and ammeter readings.
3. Increase the resistance of the rheostat by a small amount and again record the corresponding voltmeter and ammeter readings.

4. Repeat Step 3 until you have at least six pairs of voltmeter and ammeter readings.
5. Record your results in a table and calculate the ratio $\frac{V}{I}$ for each pair of readings.
6. Plot a graph showing voltage (on the y-axis) against current (on the x-axis) for your set of data.

Results

The ratio $\frac{V}{R}$ is constant for a particular resistor. Your graph should be a straight line passing through the origin.

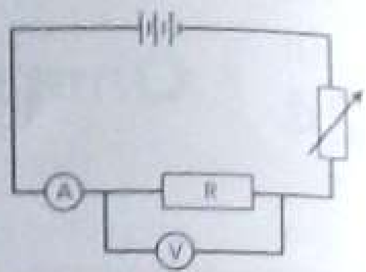


Figure 24.2 Measuring resistance

Ohm's law

The ratio $\frac{V}{I}$ of corresponding sets of values of potential difference across a resistor and the current that flows as a result is a constant. Also, for the same resistor, the graph of I compared to V is a straight line that passes through the origin. These findings are summarised in Ohm's law:

> *The current through a metallic conductor is directly proportional to the potential difference across its ends, provided the temperature and other physical conditions of the conductor remain constant.*

Mathematically, Ohm's law is stated as follows:

$R = \frac{V}{I}$ or $V = IR$

Conductors that obey Ohm's law are called **ohmic conductors**. Ohmic conductors include metals and certain alloys. **Semiconductors**, such as diodes and conduction through gases do not obey Ohm's law and are called **non-ohmic conductors**.

Limitations of Ohm's law

Under the following circumstances, Ohm's law is not obeyed by ohmic conductors:

- The temperature of the conductor changes (examples are bulbs and heater elements).
- The conductor is coiled (an example is a filament bulb).
- The conductor does not have a uniform cross-sectional area when it is under tension.
- The conductor is placed in a strong magnetic field that alters the internal structure of the metal so that its conducting capacity changes.

Factors that influence resistance

The factors that influence resistance include the length of the conducting wire as well as its cross-sectional area:

- If you measure the resistance of different lengths of wire with the same cross-sectional area, you will find that doubling the length of the wire doubles its resistance. Therefore, resistance is directly proportional to the length of the wire.
- If you measure the resistance of two pieces of wire of the same length, but of different thickness, you will find that the resistance is inversely proportional to the cross-sectional area. This means that the larger the diameter, the lower the resistance, and the thinner the wire, the higher its resistance.

Resistors in series and parallel

Resistors can be connected in series or in parallel.

Resistors in series

The total resistance for any number of resistors that are connected in series is the sum of the single resistances of each resistor (see Figure 24.3).

Total resistance $R_T = R_1 + R_2 + R_3$

Example

A 1-Ω, 2-Ω and a 3-Ω resistor are connected in series. Calculate the size of the current that would flow through them if a 6-V battery were connected across all three resistors. See Figure 24.3

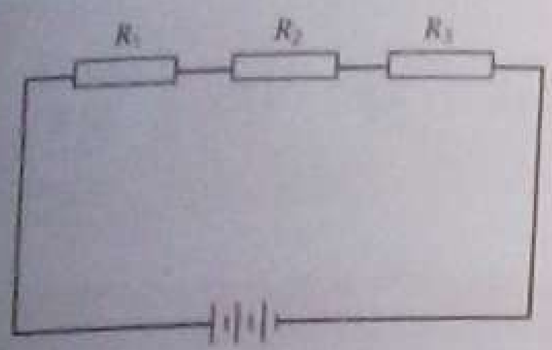


Figure 24.3 Resistors connected in series

Answer

$R_T = R_1 + R_2 + R_3$
$= 1\ \Omega + 2\ \Omega + 3\ \Omega$
$= 6\ \Omega$

From Ohm's law $I = \frac{V}{R} = \frac{6}{6} = 1$ A

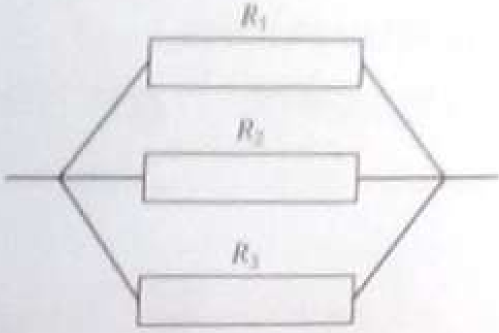


Figure 24.4 Resistors connected in parallel

Resistors in parallel

You can calculate the total resistance for three resistors in parallel (such as the ones in Figure 24.4) as follows:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad \text{or} \quad R_T = \frac{R_1 \cdot R_2 \cdot R_3}{R_2R_3 + R_1R_3 + R_1R_2}$$

For two resistors in parallel:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} \quad \text{or} \quad R_T = \frac{R_1 \cdot R_2}{R_1 + R_2}$$

Example

A 2-Ω and a 3-Ω resistor are connected in parallel. A 6-V battery is connected across the resistor network. What is the total current that flows in this circuit?

Answer

$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{2} + \frac{1}{3} = \frac{5}{6}$ so that $R_T = 1.2\ \Omega$

or $R_T = \frac{2 \times 3}{2 + 3} = \frac{6}{5} = 1.2\ \Omega$

From Ohm's law $I = \frac{V}{R} = \frac{6}{1.2} = 5$ A

Summary

- An electric current flows through a conductor when a potential difference exists across its ends.
- The potential difference across a wire is proportional to the current that passes through it.
- Ohmic conductors obey Ohm's law, provided that their temperature does not rise significantly and they are not coiled.
- Resistance is directly proportional to the length of an ohmic conductor.
- Resistance is inversely proportional to the diameter of an ohmic conductor.

Glossary

non-ohmic conductor – a conductor that does not obey Ohm's law

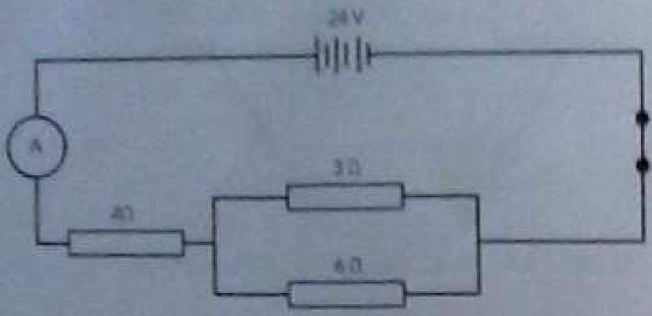
ohmic conductor – a conductor obeying Ohm's law under most conditions

rheostat – a variable resistor used to control current

semiconductor – a solid that is a non-conductor when pure or at low temperatures

Revision questions

1. Given the following circuit:



   a) What is the combined resistance of the parallel combination? (3)
   b) What is the total resistance of the circuit? (3)
   c) What would the ammeter reading be? (3)
   d) Calculate the potential difference across the parallel combination of resistors. (3)
   e) Calculate the potential difference across the 4-Ω resistor. (3)
   f) How much current passes through the 3-Ω resistor? (3)
   g) Calculate the current that passes through the 6-Ω resistor. (3)
2. When do ohmic resistors no longer obey Ohm's law? (2)
3. How is the resistance of a wire related to its length and diameter? Describe an experiment to prove these relationships. (6)

TOTAL: 29

Unit 25 Electrical power and energy

Objectives

- Define electrical power and energy.
- Calculate electrical power and energy.

Introduction

Electricity is the type of energy that is most often used in houses and other buildings. Electricity has made our lives a lot more comfortable. When electricity is handled properly, it is safe to use. However, if it is misused, it can be deadly.

Uses of electricity in the home

We have many uses for electricity in our homes. Examples include heating and lighting. Most of the appliances in our homes use electricity. Electric motors and other devices convert electrical energy into mechanical energy. There are many appliances that use electrical motors such as lawn mowers, vacuum cleaners, fans and hairdryers.

Power and energy

A resistor, such as an electric heater element or bulb, converts electrical energy to heat and light. The rate at which this type of appliance converts electrical energy to heat and light is its power. We use the following formula to calculate the amount of electrical energy that an appliance converts to another type of energy:

electrical energy = voltage × current × time

$(E = VIt)$

Power is measured in joules per second, or in watts (W). It is the rate of using energy (1 W = 1 J/s).

power = voltage × current $(P = VI)$

The cost of electricity

A utility company such as the Zimbabwe Electricity Supply Authority (ZESA) charges households and companies for the electrical energy that it supplies to them. In most high-density suburbs, households are fitted with amp limiters. Customers who have these amp limiters are charged a fixed amount for the electricity that they consume – it does not matter how much they consume. Other households and companies have electricity energy meters (see Figure 25.1). These meters measure the amount of electrical energy that is consumed. The unit for electrical consumption is the kilowatt hour (kWh). It is the electrical energy used by a 1-kW appliance in one hour. One unit of energy is called the kWh. For example, a 2-kW heater that works for two hours consumes 4 kWh of electricity, or four units.

Figure 25.1 An electrical energy meter

Example

Assuming a unit of electricity costs 8 c, calculate the cost of burning an electric stove at 8000 W for 4 hours.

Answer

$\text{Power} = \frac{\text{energy transferred}}{\text{time}}$

Thus energy = power × time
= 8000 W × 4 h
= 32 kWh
= 32 units

So, cost = 1 unit × 8 c
= 32 units × 8 c
= $2.56

Project

In groups, research the topic of electric energy in Zimbabwe. You have to find out which energy sources are used in supplying electricity to Zimbabwean homes. Choose two or three different sources and compare the advantages and disadvantages of these sources in the Zimbabwean context. Conclude by choosing the best option for Zimbabwe.

Marks will be awarded according to the following criteria:

Written report

1.	Structure	(3)
2.	Content/conclusion	(10)
3.	Neatness	(2)
4.	List of resources consulted	(5)
		TOTAL: 20

Safe use of electricity

Electricity is very useful, but it can be deadly if it is not used safely.

Broken plugs and frayed wires can expose the metal wires or parts of the plug that carry electricity. Touching these wires would give you an electric shock. It is thus important that these wires should be replaced as soon as they are damaged. Anyone who pokes a metal object into a mains socket will also get an electric shock. Cables to electrical appliances should be kept as short as possible. Water can conduct electricity at high voltages, so water should be kept away from sockets and you must never use electrical appliances if your hands are wet. A short-circuit occurs when a bare live wire (brown or red) touches a bare neutral wire (black or blue). When this happens, sparks are produced and a large current flows through the wires. This results in overheating and the insulation burning. This can start a fire. Circuits should not be overloaded. A circuit is overloaded when it is forced to deliver more current than it was designed to deliver. Electrical cables heat up due to overloading.

Main power supply safety in the home

In the case of electricity supply to a building, the main power supply is connected in series to a meter box, measuring electricity consumption, and a **circuit breaker box**, containing safety components in the case of overload or short-circuit.

The circuit breaker box contains a **fuse** and an **earth leakage circuit breaker** in series to the main line, after which it divides the main supply into parallel lines with individual **circuit breakers**. The functions of these three components are as follows:

- Circuit breaker: an electronic switch that interrupts current flow
- Fuse: made from a metal with a low melting point (If the current is too strong, the fuse wire will melt and interrupt the circuit.)
- Earth leakage: will break the circuit if anything connects the circuit with the Earth.

Electrical safety in the home

- Disconnect the main circuit breaker before doing any repair work on electrical appliances.
- Use insulating tape to cover open connections.
- Immediately replace damaged plugs on appliances.
- Keep electrical appliances away from water

Summary

- Electrical energy flows through a current when it is connected to a power source and it is measured in joules.
- The rate at which an appliance converts electrical energy to heat and light is its power and is measured in watts.
- A utility company charges households and companies for the electrical energy that it supplies to them.
- Electrical energy consumed by appliances is measured in kWh (kilowatt hours), which is how much power a 1kW appliance would use in 1 hour.

Glossary

circuit breaker box – box in building containing safety components in the case of overload or short-circuit

circuit breaker – an electronic switch that interrupts current flow

earth leakage circuit breaker – circuit breaker in series to the main line, after which it divides the main supply into parallel lines

fuse – device made from a metal with a low melting point to break the circuit if the current becomes too strong

Revision questions

1. Assuming a unit of electricity costs 8 c, calculate the cost of burning a 100 W light bulb for 5 hours. (2)
2. You use a 2000 W heater for 5 hours each night in the month of June, and the cost of a unit is 15c, how much does this contribute towards the total electricity bill for the month of June? (2)
3. Define the term 'power'. (1)
4. What is the difference between electrical energy and electrical power? (2)
5. Which three safety mechanisms are installed in homes to ensure the safe use of electricity? (3)

TOTAL: 10

End of topic revision test

1. A student counted the number of different insects in an area of the school garden and found the following categories and numbers:

beetles	3
butterflies	8
grasshoppers	2
earthworms	11
centipedes	6

   a) Use the data to draw a pie chart. (7)
   b) What percentage of all insects in the garden were earthworms? (1)

2. a) Describe how to use Vernier callipers to measure the internal diameter of a pipe. (2)
   b) A toy with a mass of 10 g is submerged in water, raising the water level by 5 mℓ. Calculate the density of the toy. (3)

3. a) State Newton's three laws. (3)
   b) An object with a mass of 15 kg is moving at a speed of 2 m/s. Calculate its momentum. (3)

4. A lever system to move a large rock is set up as follows:
   Pivot to effort distance = 8 m
   Pivot to load distance = 3 m
   Weight of rock = 1 000 N
   a) What is the velocity ratio of the lever? (2)
   b) State the effort needed to move the rock. (1)
   c) What is the mechanical advantage of the lever system? (2)

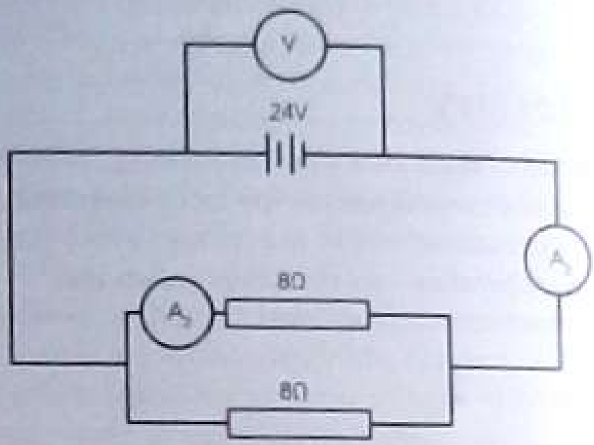
5. Define efficiency. (1)

6. Describe the four-stroke action of a petrol engine. (4)

7. Define the following terms:
   a) convection
   b) conduction
   c) radiation. (3)

8. a) What does the abbreviation emf stand for? (1)
   b) Name the factors that influence the magnitude of an induced emf. (4)
   c) How does a DC motor differ from an AC motor? (2)

9. For the following circuit:



   a) Calculate the effective resistance. (2)
   b) Calculate the reading on Ammeter A_1. (2)
   c) Calculate the reading on Ammeter A_2. (2)

10. Your radio uses 200 W for 5 hours each day in the month of June and the cost of a unit is 15 c.
    How much does this contribute towards the total electricity bill for the month of June? (2)

11. Define the term power. (1)

12. What is the difference between electrical energy and electrical power? (2)

TOTAL: 50

Index

step ahead

Combined Science

FORM 3

Step Ahead Combined Science Form 3 is part of a new course especially developed to meet the needs of the 2015–2022 Zimbabwe Education Curriculum Framework.

The course seeks to develop learners who:

- are keenly aware of the values, ethos and attitudes necessary for the growth and development of our country
- realise that they already have natural talents and skills which they can build on, so that they are able to function beyond the classroom as effective citizens of Zimbabwe.

The Learner's Book addresses all aims and specific outcomes of the Combined Science syllabus. It contains:

- carefully drawn artwork and colour photographs
- varied activities and exercises designed to foster key skills, like critical thinking, problem-solving, leadership, ICT, communication and team-building.

The Teacher's Guide contains:

- useful background information for the teacher
- hints on how to teach concepts well
- answers to activities, exercises and assessments.

This course has been approved for use in schools by the Ministry of Primary and Secondary Education.