MINISTRY OF EDUCATION

GHANA ASSOCIATION OF SCIENCE TEACHERS

(GAST)

General Science

for Senior High Schools

Year 3



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FOREWORD

Ghana's new Senior High School Curriculum aims to ensure that all learners achieve their potential by equipping them with 21st Century skills, knowledge, character qualities and shared Ghanaian values. This will prepare learners to live a responsible adult life, progress to further studies and enter the world of work. This is the first time that Ghana has developed a Senior High School Curriculum which focuses on national values, attempting to educate a generation of Ghanaian youth who are proud of our country and can contribute effectively to its development.

The Ministry of Education is proud to have overseen the production of these Learner Materials which can be used in class and for self-study and revision. These materials have been developed through a partnership between the Ghana Education Service, teacher unions (Ghana National Association of Teachers-GNAT, National Association of Graduate Teacher -NAGRAT and the Pre-Tertiary Teachers Association of Ghana- PRETAG) and National Subject Associations. These materials are informative and of high quality because they have been written by teachers for teachers with the expert backing of each subject association.

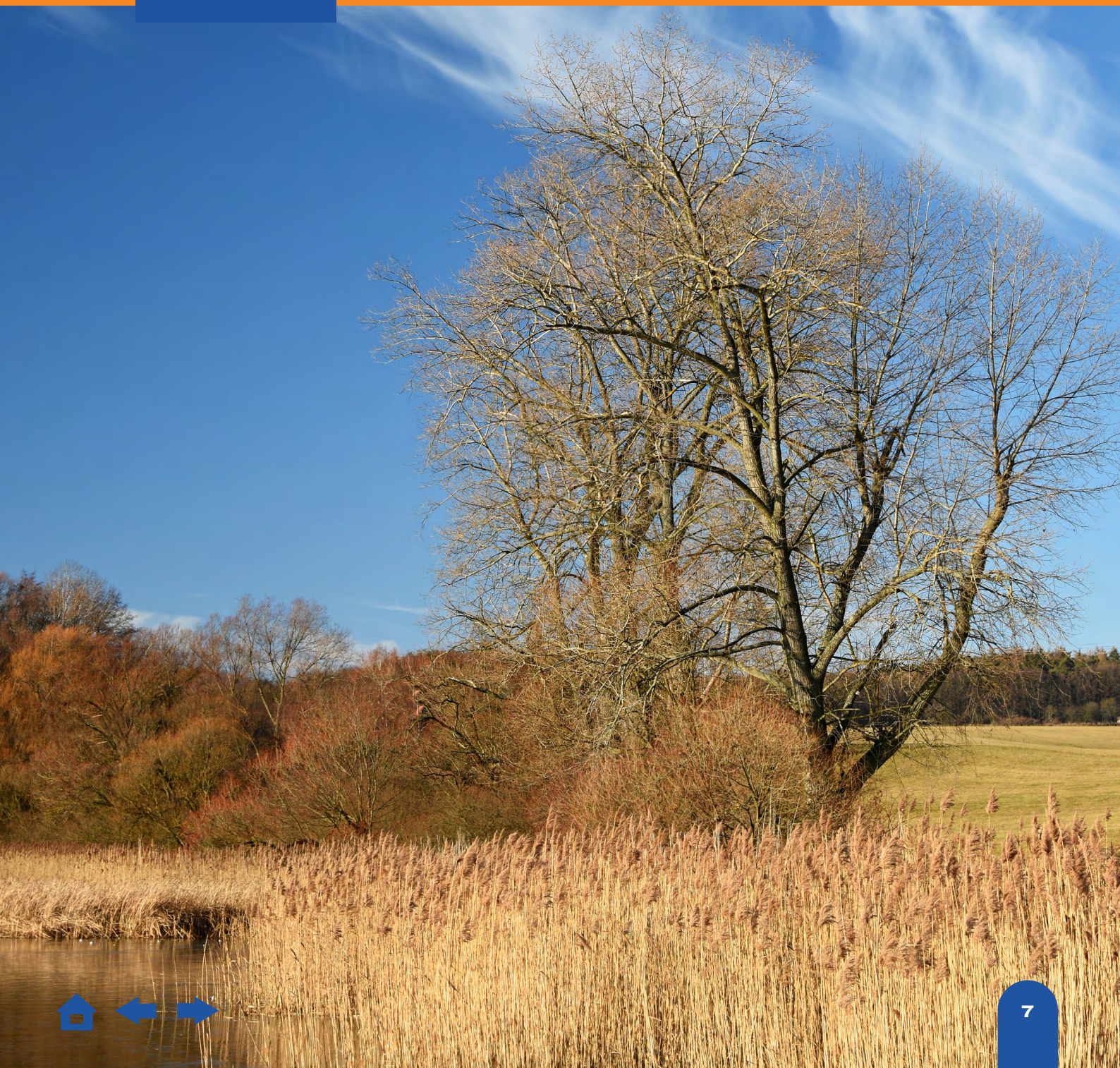
I believe that, if used appropriately, these materials will go a long way to transforming our Senior High Schools and developing Ghana so that we become a proud, prosperous and values-driven nation where our people are our greatest national asset.

Haruna Iddrisu MP
Minister for Education

SECTION

1

COMPOSITION OF AIR



EXPLORING MATERIALS

INTRODUCTION

In this section, you will learn that air is made up of different gases. You will discover the main gases found in air and understand how they are useful in nature and in our daily lives. Through simple experiments, you will learn how to prepare carbon dioxide and oxygen in the lab, explore their properties, and identify their uses.

By the end of the lesson, you should be able to describe what air is made of, explain the role of each gas, and demonstrate how to make carbon dioxide and oxygen, as well as explain their uses.

KEY IDEAS

- **Air is a mixture of gases:** Air is made up of many gases, not just one. These include nitrogen, oxygen, carbon dioxide, and others.
- **Carbon dioxide helps plants make food**: Plants use carbon dioxide to make their food through photosynthesis.
- **Nitrogen is the most common gas in air**: Nitrogen makes up most of the air and is used to help plants grow.
- **Oxygen is needed for breathing and burning:** We need oxygen to stay alive, and it also helps things burn.
- **Small gases have big uses**: Gases like helium and ozone are found in tiny amounts but are useful in lights, medicine, and protecting the Earth.

COMPONENTS OF AIR AND THEIR USE

Meaning of Air

Air is an invisible mixture of gases (mainly of oxygen and nitrogen that cover the earth, each present in different proportions. These gases work together to:

1. Support life on Earth
2. Influence weather patterns
3. Enable industrial processes.

Properties of Air

1. **Air has mass:** Even though we cannot see it, air is made up of particles and therefore has mass. This can be shown by weighing a deflated balloon and then weighing it again when filled with air; the balloon becomes heavier.
2. **Air occupies space:** Air takes up space, even though it is invisible. For example, when you blow air into a balloon, it expands because air fills it.
3. **Air is compressible:** Air can be squeezed into a smaller space. This is why pumps can force more air into tyres or balls.
4. **Air exerts pressure:** The particles in air constantly move and collide with surfaces, creating air pressure. This is why inflated tyres or football stay firm.
5. **Air supports burning:** Oxygen in air helps things burn. A fire will go out if there is no air or not enough oxygen.



Figure 1.1: Properties of air

Rather than being a single pure substance, air is made up of various gases in specific proportions. These are nitrogen, oxygen, carbon dioxide, argon, water vapour and trace gases such as neon and helium. Each of these components plays a vital role in environmental processes and human activities.

Understanding air as a mixture helps us appreciate how these gases interact to support breathing, combustion, plant growth, industrial processes, and climate regulation.

Composition of Air

Table 1.1: Components of clean dry air and their percentage composition

Component of air	Volume by %	Symbol of the gaseous element
Nitrogen	78.08	N_2
Oxygen	20.95	O_2

Argon	0.93	Ar
Carbon Dioxide	0.040	CO_2
Other gases (trace gases)		
Neon	0.0018	Ne
Helium	0.0005	He
Krypton	0.0001	Kr
Hydrogen	0.00005	H_2
Xenon	8.7 x 10 -6	Xe

1. Nitrogen Gas

Nitrogen gas is a colourless, odourless, and tasteless substance that makes up about 78% of the air we breathe. It exists as two atoms chemically joined together (N_2) and does not support burning or breathing. Nitrogen is very important for living things because it helps in the formation of proteins in plants and animals. In industry, it is used to make fertilisers, explosives, and ammonia, and it is also used to preserve packaged foods by preventing spoilage.

Uses of Nitrogen gas

Nitrogen plays a crucial role in various natural and industrial processes. Here are some of its main uses:

a. **Agriculture (Fertilisers):** Nitrogen is a key component of fertilisers such as urea and ammonium nitrate. Plants need nitrogen for growth as it helps in the formation of proteins and chlorophyll.

b. **Biological importance:** Nitrogen is found in all living organisms as part of amino acids, proteins, enzymes, and deoxyribonucleic acid (DNA). It is essential for cell development and reproduction.

c. **Food industry:** Nitrogen gas (which is inert, meaning it does not react with food components or change their flavour, aroma, or texture) is used to preserve packaged foods by displacing oxygen (which is the main cause of food spoilage through oxidation and the growth of aerobic bacteria) to prevent spoilage and bacterial growth.

d. **Industrial applications**:

i. Used to create an inert atmosphere in chemical processes and electronics manufacturing to prevent oxidation

ii. Used in the production of ammonia (NH_3) through the Haber process, which is the foundation of many nitrogen-based products.

e. **Medical uses**: Liquid nitrogen (which has the ability to instantly freeze) is used for cryosurgery, which involves freezing and removing abnormal or diseased tissues, such as warts or precancerous cells.

f. **Inflating aircraft and car tyres:** Nitrogen is preferred in tyres because it is less likely to cause pressure changes due to temperature fluctuations and reduces oxidation inside the tyre.

2. Oxygen gas (O_2)

Oxygen is one of the most vital chemical elements in the air, represented by the symbol 'O' and atomic number 8. It is a highly reactive and combustible gas that forms compounds called oxides with other elements. Oxygen ranks third in abundance by mass in the universe, after hydrogen and helium. At standard temperature (273.15K) and pressure (1 atm), two atoms of oxygen form a molecule called dioxygen (O_2), essential for respiration in living organisms.

Uses of oxygen

a. **Respiration**: Oxygen is essential for aerobic respiration in humans and animals. It is the gas we breathe in to help break down food and release energy in cells. Without oxygen, most living organisms cannot survive, as it plays a key role in cellular energy production.

b. **Medical applications:** Oxygen is widely used in hospitals and healthcare settings:

   i. Oxygen therapy is provided to patients with breathing difficulties or respiratory conditions like asthma, pneumonia, and COVID-19.

   ii. It is also used in anaesthesia machines during surgeries.

   iii. Ambulances and emergency services carry oxygen cylinders for immediate first aid.



Figure 1.2: A patient on oxygen support

c. **Industrial Processes**: Oxygen is used in a range of industrial applications:

i. Steel manufacturing: Oxygen is blown into molten iron to remove impurities like carbon, producing high-quality steel.

ii. Chemical production: It is used in making chemicals such as nitric acid and hydrogen peroxide.

iii. Welding and cutting: Oxygen is used in combination with gases like acetylene in oxy-acetylene torches for welding, cutting, and brazing metals.

d. **Aviation and space exploration**: In high-altitude aviation and space missions, oxygen is supplied in tanks to pilots and astronauts since the atmospheric oxygen is too low or absent at those altitudes. It ensures proper breathing and life support.

e. **Water treatment:** Oxygen is used in wastewater treatment plants to help break down pollutants by supporting the growth of aerobic bacteria. It improves the efficiency of the biological treatment process.

f. **Scuba diving:** Scuba divers carry compressed oxygen tanks to breathe underwater.



Figure 1.3: Scuba diver with compressed oxygen tank under water

g. **Environmental and laboratory uses**

i. In environmental studies, oxygen sensors measure water quality by checking dissolved oxygen levels.

ii. It supports aquatic life, such as fish and other aquatic organisms depends on it as an essential component.

3. Carbon Dioxide Gas (CO_2)

Carbon dioxide is represented by the chemical symbol 'CO_2'. Carbon dioxide is released during respiration and the decomposition of organic matter. It also occurs naturally from sources such as volcanoes, geysers, and hot springs. Additionally, the burning of fossil fuels like petroleum and natural gas produces significant amounts of carbon dioxide.

Uses of Carbon dioxide

a. **Photosynthesis:** Carbon dioxide plays a crucial role in the survival of plants through the process of photosynthesis. During this process, plants absorb carbon dioxide from the atmosphere and use it, along with sunlight and water, to produce

glucose (a form of sugar) and oxygen. This is not only essential for plant growth but also vital for maintaining the oxygen balance in the atmosphere.

b. **Food and beverage industry:**

   i. Carbonation: CO_2 is widely used to carbonate beverages such as soft drinks, soda water, and sparkling wine, giving them their fizzy properties.

c. Preservation: In packaged foods, carbon dioxide is used to keep food fresh, preventing spoilage. It preserves food by inhibiting the growth of microorganisms and slowing down the natural degradation of food. Unlike nitrogen, which is mostly used to displace oxygen, CO2 has specific **antimicrobial properties** that actively interfere with bacterial survival. **Fire extinguishers**: Carbon dioxide is commonly used in fire extinguishers, especially for electrical fires and flammable liquids. It works by displacing oxygen around the fire and forming a blanket over the flames, thus cutting off the oxygen supply required for combustion.

d. **Refrigeration (dry ice):** In its solid form, carbon dioxide is known as dry ice. It is used as a cooling agent for the preservation of perishable goods such as meat, seafood, and medical supplies during storage and transport. Dry ice sublimes directly (into gas without passing through a liquid phase), making it very convenient for refrigeration without any mess.

e. **Welding and industrial use**: In industries, carbon dioxide is used as a shielding gas in gas metal arc welding (GMAW). It protects the welded area from atmospheric gases such as oxygen and nitrogen that could cause defects in the welded work. CO_2 is also used in the production of certain chemicals and plastics.

f. **Greenhouses:** A greenhouse is a structure designed to create a controlled, warmer environment for growing plants. It works by trapping solar radiation, preventing heat loss through convection and conduction. Carbon dioxide enrichment in greenhouses is a common practice used to promote faster and healthier plant growth. By increasing the concentration of CO_2 in the air within a greenhouse, plants can photosynthesise more efficiently, resulting in better yields.

g. **Fertiliser production**

   i. CO_2 is an important raw material in the manufacture of urea, a nitrogen-based fertiliser used globally in agriculture.

   ii. Urea (NH_2CONH_2) is formed when carbon dioxide reacts with ammonia under specific conditions. This fertiliser helps to increase crop yield and is vital for food production.

$CO_2 + 2\ NH_3 \rightarrow NH_2CONH_2 + H_2O$

4. Water Vapour

Its amount varies depending on location and weather. It plays a vital role in cloud formation, rainfall, and temperature regulation through the greenhouse effect. Water vapour content in the air varies from 0.01% to 4.24%, depending on temperature. It is released during respiration and produced in many chemical reactions.

As an important gas in the atmosphere, it helps keep the Earth warm by regulating temperature (trapping heat); water vapour is a natural greenhouse gas. It absorbs and releases heat in the atmosphere, keeping our planet warm.

This is important for us for the following reasons

a. **Supporting life**: This helps maintain a temperature that is just right for plants, animals and humans to thrive.
b. **Makes Earth a comfortable home:** Helps in weather formation (Water Cycle): Water vapour is a factor in weather systems. It contributes to cloud formation, storms, and rainfall.

    i. In the water cycle, it helps form clouds; water vapour turns into clouds, makes rain and snow.
    ii. Helps regulate temperature; Water vapour keeps Earth's temperature stable.



5. Trace gases

Trace gases are gases that are present in small amounts in the air.

Even though they are present in tiny amounts, these gases can be very important for

a. **Technology**: making neon signs and helium balloons.
b. **Environment**: Some trace gases can affect the climate.
c. **Industry**: They are used in various products and processes.

Even though trace gases make up less than 1% of the atmosphere, they can have a big impact.

Table 1.2: Uses of trace gases

Gas	Use
Argon	In bulbs, electronics and eye surgery.
Neon	Glows in advertising signs.
Helium	Fills balloons, cools MRI machines.

Methane	Fuel for cooking and electricity.
Krypton	In bright lights and insulated windows.
Hydrogen	As rocket fuel, in green energy.
Ozone/Oxone	Protects us from harmful sun rays and purifies water and air.

Perform the activity below in a group of four members, record and discuss your observations as a group.

Activity 1.1 Demonstrating effects of air on substances

What you need

- A shallow dish or plate
- Water
- Food colouring (optional, for better visibility)
- A candle
- A lighter or matches
- A clear, wide-mouthed glass or jar

What to do

1. Pour water into the dish and add food colouring if desired.
2. Place the candle in the centre of the dish and light it.
3. Carefully place the glass or jar over the burning candle, ensuring the bottom edge of the glass is submerged in the water.
4. Watch what happens to the candle and the water level as the candle burns.
5. Read and record your observation.

See **Annex 1.0** on **page xxxx** for expected observations for activities.

Key questions

1. Which gas's presence is indicated by the ability of the candle to burn?
2. What happens to the candle after burning for some time?
3. What happens to the level of water inside the glass?
4. Explain your observations in 1 and 2 above.

Safety precautions

1. Do not use plastic containers, as they can easily deform due to the changes in temperature of the air.
2. Move any inflammable substance away before lighting the candle.

Activity 1.2 Simulation of the behaviour of air

Aim: Verify that Air Occupies Space

What you need

- Empty glass
- Bowl of water

What to do

1. Invert the glass and push it straight down into the water.
2. Record your observations and explain why they suggest that air occupies space.

Activity 1.3 Video to reinforce understanding of properties of air

Click on the video link below to reinforce your understanding of the properties of air

https://youtu.be/I3JtnoCnQ7w?si=078fND0fchPc0M7N

Activity 1.4 The components of air

What to do

1. Develop a data table or model which represents the components of air (see **Annex 1.0** for solutions).
2. Evaluate the roles of each of the components of air in sustaining life.
3. Consider how a change in air composition could impact the environment.
4. Explain why air is described as a mixture rather than a compound.

Activity 1.5 Research project

Objective: To explore the composition of air and understand its roles in supporting life and natural processes.

Instructions

1. **Introduction**
   a. Define what air is.
   b. Briefly describe why studying air is important.
2. **Components of Air**
   a. Identify the major gases in air (nitrogen, oxygen, carbon dioxide, etc.).
   b. Include minor components like water vapour and noble gases.

c. Explain how these components vary in different environments (e.g., polluted cities vs. forests).

3. **Uses of Air in Nature**
   a. Discuss how plants use air (photosynthesis and respiration).
   b. Explain how animals and humans rely on oxygen for survival.
   c. Describe natural processes such as wind, pollination, and weather cycles.
   d. Mention the role of air in supporting fire and energy cycles.
4. **Environmental Importance**
   a. Explore how clean air is essential for ecosystems.
   b. Briefly touch on the effects of air pollution on nature.
5. **Conclusion**
   a. Summarise the importance of air's components and uses.
   b. Reflect on why protecting air quality matters for the future.
6. **Presentation**
   a. Present findings as a poster with diagrams.
   b. Include at least 2 visuals (e.g., a pie chart of air composition, a diagram of photosynthesis).
   c. Cite at least 3 reliable sources.

PREPARATION OF CARBON DIOXIDE AND OXYGEN GAS AND THEIR USES

Dear learners, you are welcome to another exciting aspect of our studies. In our previous lesson, we studied the components of air, a mixture which includes oxygen and carbon dioxide. We saw their respective percentage compositions and various uses to which they are put. However, do these gases only exist naturally, or can they also be prepared? This week, we are going to learn about how carbon dioxide and oxygen can be prepared, in the laboratory, by way of chemical reactions. We shall also learn about their physical and chemical properties, as well as the various uses to which they can be put in everyday life activities. You will look at the following areas:

a. Physical and chemical properties of carbon dioxide and oxygen.
b. Preparation of carbon dioxide and oxygen gases using available materials.
c. Test for carbon dioxide and oxygen.

Carbon dioxide (CO_2) and oxygen (O_2) are vital gases which are used in a variety of everyday activities across various disciplines such as science, industry, agriculture, medicine and preservation of the natural environment.

CO_2 is absorbed by plants and plankton during photosynthesis, which releases oxygen. Humans and animals, in turn, inhale oxygen and exhale CO_2, which is also released through decomposition and combustion. While oxygen is necessary for respiration and combustion, CO_2 is a greenhouse gas that absorbs and re-radiates heat, trapping it in the atmosphere. Human activities have disrupted the natural balance of this cycle, leading to increased atmospheric CO_2 levels.

Carbon dioxide is also used in the production of carbonated beverages, fire extinguishers and serves as a crucial reactant in various chemical processes.

Oxygen is also widely used in industrial processes such as steelmaking, welding, and medical applications.

Laboratory preparation of carbon dioxide and oxygen gases

In this lesson, we are going to use various methods to prepare both carbon dioxide and oxygen in the laboratory. We shall study the principles of the reactions involved, the necessary materials and apparatus used, step-by-step approaches, critical safety precautions, and the scientific reasons for choosing specific materials and methods.

Laboratory Preparation of Carbon Dioxide (CO_2)

Carbon dioxide gas is commonly prepared in a laboratory by reacting an acid (usually dilute) with a carbonate or hydrogen carbonate of a metal. An example of such a reaction is the action of dilute hydrochloric acid on calcium carbonate (marble chips) in a test tube or conical flask.

The reaction produces calcium chloride, water, and carbon dioxide gas, which can then be collected by upward displacement of air because it is denser than air.

The balanced chemical equation for this reaction is:

$$\mathbf{CaCO_{3(s)} + 2HCl_{(aq)} \rightarrow CaCl_{2(aq)} + H_2O_{(l)} + CO_{2(g)}}$$

In the reaction, one mole of solid calcium carbonate reacts with two moles of aqueous hydrochloric acid to produce one mole of aqueous calcium chloride, one mole of liquid water, and one mole of gaseous carbon dioxide. The precise molar ratios are necessary for determining the needed amounts of reactants so as to help predict the theoretical yield of the product.

The reaction does not need external heating or additional energy input since it proceeds spontaneously at room temperature. This makes the method a practical choice for laboratory use.

Diagram: The chemicals and other equipment used are shown in the setup below.

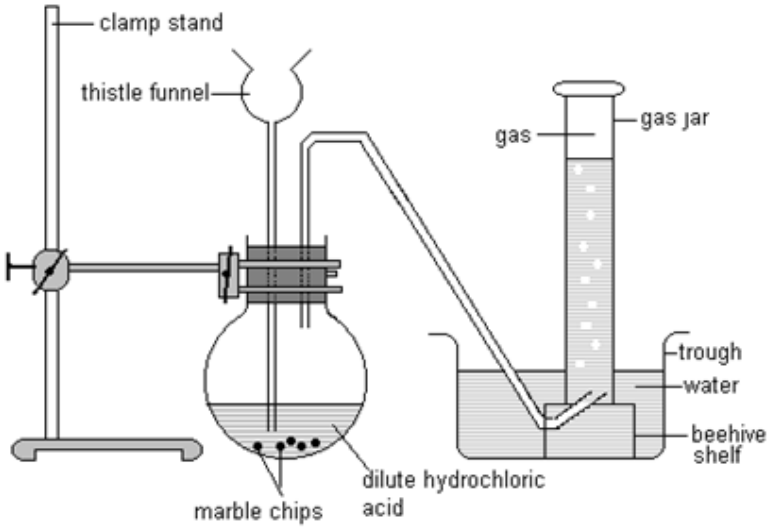


Figure 1.4: Setup for preparation of carbon dioxide gas.

This type of reaction is classified as an acid-carbonate reaction, and it proceeds spontaneously at room temperature. The fact that the reaction occurs readily without external heating simplifies the experimental setup and reduces the need for additional energy input, making it a practical choice for laboratory use.

Key question

What other methods can you use to prepare carbon dioxide gas?

Now, in a group of five people, prepare carbon dioxide gas using the materials provided and the procedures listed below. **Do this activity under the supervision of an adult.**

Activity 1.6 Preparing and testing carbon dioxide gas

Aim: To prepare CO_2 and use it to put out a fire.

What you need

- Baking soda (sodium bicarbonate) - 2 tablespoons
- White vinegar /lemon/lime juice - 100ml
- Large plastic bottle (500ml or 1 litre)
- Balloon
- Funnel (or rolled paper)
- Drinking straw
- Candle and lighter/match
- Spatula and beaker

What to do

Step 1: Set up

a. Pour the vinegar into the plastic bottle (about 1/3 full).

b. Using the funnel, carefully add baking soda to the balloon.

c. Stretch the balloon's opening over the bottle neck without letting baking soda fall into the bottle yet.

Step 2: Gas production

a. Lift the balloon to let all the baking soda fall into the vinegar.

b. Watch the immediate fizzing reaction.

c. The balloon will inflate as CO_2 gas is produced.

d. Wait 2-3 minutes for maximum gas production.

Step 3: Collecting the gas

a. Carefully remove the balloon from the bottle.

b. Twist the balloon's neck to keep gas inside.

c. Record your observation

Step 4: Testing

a. Light the small candle.

b. Carefully release the invisible CO_2 gas from the balloon into the candle flame

c. Write down your observation in your notebook.

Chemical Reaction

Baking soda + Vinegar → Salt + Water + Carbon dioxide

$NaHCO_3 + CH_3COOH \rightarrow CH_3COONa + H_2O + CO_2$

Safety precautions

1. Avoid spillage of chemicals.
2. Wash any chemical that gets in contact with your body immediately with a lot of water.
3. Do not ingest (do not taste or drink) the vinegar.
4. Do not put the lighter near any combustible substance.

Key question

What shows that a gas was produced? Write down the answer to this question in your notebook.

Activity 1.7 Test for carbon dioxide (CO_2) in exhaled air

Aim: To show CO_2 is present in exhaled air.

What you need

- Delivery tube
- Lime water
- Rubber cork
- Test tube containing CO_2

What to do

1. Prepare lime water by dissolving about 5g of calcium hydroxide [$Ca(OH)_2$] in water.
2. Bubble the CO_2 gas through the limewater out of your mouth. You can use a straw, tubing, or a delivery tube to gently pass the gas through the limewater.
3. Look carefully and write down your observation of the reaction.

Chemical equation of the reaction

$CO_2\ (g) + Ca(OH)_2\ (aq) \rightarrow CaCO_3\ (s) + H_2O\ (l)$

This is a standard and reliable test for detecting carbon dioxide gas.

Safety precautions

1. **Use clean apparatus**: Ensure the delivery tube and beaker are washed before and after the experiment to avoid contamination.
2. **Do not share mouthpieces**: Each student should have their own straw or tube to prevent spreading germs.
3. **Avoid swallowing limewater**: Limewater (calcium hydroxide solution) is mildly caustic; do not drink it.
4. **Rinse immediately if spilt**: If limewater comes into contact with skin or eyes, wash thoroughly with clean water.
5. **Use small amounts**: Only a small quantity of limewater is needed to reduce risk.
6. **Dispose safely**: Pour used limewater into a designated waste container, not down sinks without teacher permission.
7. **Work under supervision**: Always experiment with a teacher or lab supervisor present.

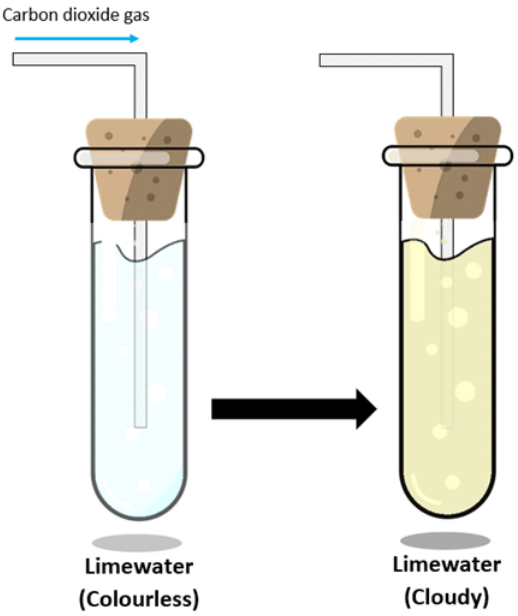


Figure 1.5: Testing for carbon dioxide.

Real-world application

Atmospheric carbon dioxide plays a crucial role in the formation of calcium carbonate rocks like limestone. It dissolves in water, forming carbonic acid, which then reacts with rocks, dissolving calcium and other ions. These ions are transported to the ocean and, along with marine organisms, contribute to the precipitation of calcium carbonate, which, over time, forms sedimentary rock.

Other processes which produce CO_2 gas

1. **Combustion**: Burning of fossil fuels (coal, oil, natural gas), organic materials (wood, paper, etc.).
2. **Respiration**: Both aerobic and anaerobic respiration in living organisms.

   During cellular respiration, glucose reacts with oxygen to produce carbon dioxide, water, and energy. Decomposition of organic matter by bacteria also releases carbon dioxide.
3. **Fermentation**: In brewing and bread making, fermentation processes produce carbon dioxide.

Key question

Describe the process of bread making, explaining the scientific principles involved, which led to the formation and release of carbon dioxide gas.

Table 1.3: Comparison of laboratory preparation methods for carbon dioxide

Method	Reactants	Products (excluding CO_2)	Conditions	Advantages	Disadvantages
Reaction of calcium carbonate ($CaCO_3$) with HCl	$CaCO_3$, HCl	$CaCl_2$, H_2O	Room temperature	Readily available reactants, relatively	Requires an airtight apparatus
Reaction of baking soda with vinegar	$NaHCO_3$, CH_3COOH	CH_3COONa, H_2O	Room temperature	Simple and safe, readily available at home	May produce CO_2 mixed with air
Thermal decomposition of $CaCO_3$	$CaCO_3$	CaO	High temperature	Produces, relatively, pure CO_2 if done correctly	Requires high temperature, is energy-intensive

Laboratory Preparation of Oxygen (O_2) gas

Oxygen gas can be prepared in the laboratory by a number of methods as follows:

1. Electrolysis of water.
2. Catalytic decomposition of hydrogen peroxide.
3. Heating metal oxides or oxo-compounds such as potassium chlorate
4. Photosynthesis of pond weed.

All of the methods above are preferred laboratory choices due to the availability of the chemicals and other materials involved.

Catalytic Decomposition of Hydrogen Peroxide

This method is most preferred due to its relative convenience and safety. Also, its reaction does not require high temperatures to take place.

In this reaction, hydrogen peroxide breaks down into water and oxygen gas in the presence of manganese (IV) oxide (MnO2) as a catalyst.

The balanced chemical equation for this reaction is: $\mathbf{2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)}$

In the equation, two moles of aqueous hydrogen peroxide decompose to yield two moles of liquid water and one mole of gaseous oxygen.

MnO_2, as a catalyst, accelerates the rate of the decomposition of hydrogen peroxide without itself undergoing any permanent chemical change. The catalyst can be recovered chemically unchanged at the end of the reaction.

Now, let us prepare and test for oxygen gas.

Perform this activity in a group of four members.

Activity 1.8a Preparation and testing of oxygen gas

Aim: To prepare and test for oxygen gas

What you need

- 3% hydrogen peroxide (from pharmacy/first aid kit) - 100ml
- Fresh raw potato - 1 medium piece
- Large clear plastic bottle (500ml)
- Small balloon or plastic bag
- Knife
- Funnel or spoon

What to do

1. Cut the potato into small cubes (about 1cm pieces).
2. Pour hydrogen peroxide into the plastic bottle.
3. Drop potato pieces into the hydrogen peroxide.
4. Immediate fizzing and bubbling begin.
5. Quickly stretch a balloon over the bottle opening to collect the oxygen gas.
6. Fasten the mouth of the balloon to keep the oxygen gas in it.
7. Record your observation.

Chemical Reaction

Hydrogen peroxide → water + oxygen gas

$2H_2O_2 \rightarrow 2H_2O + O_2$ (catalysed by potato enzyme, which is readily available instead of manganese (IV) oxide).

Expected safety precautions

1. Always wear safety goggles to protect the eyes.
2. Handle hydrogen peroxide with care as it can cause skin irritation and burns.
3. Use the knife carefully while cutting the potato
4. Do not direct the glowing splint to yourself or anyone before rekindling

Troubleshooting

1. If no bubbles form
    a. Check if the hydrogen peroxide is fresh (old peroxide loses effectiveness).
    b. Ensure potato is fresh and not cooked.
    c. Use more catalyst (potato pieces).
    d. Warm the reaction mixture to a higher temperature.

2. If the reaction is too vigorous
    a. Use less catalyst.
    b. Add catalyst slowly.
    c. Use cooler hydrogen peroxide.
    d. Work with smaller quantities of reactants.

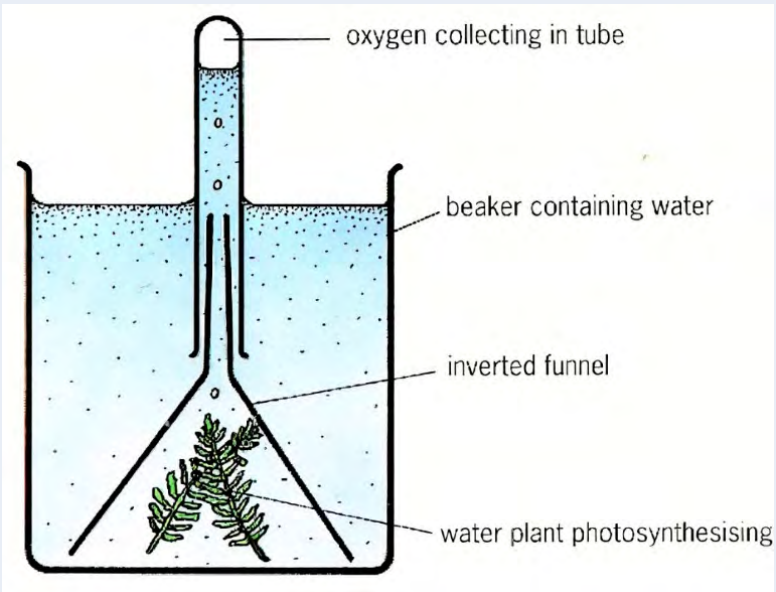
Activity 1.8b Alternative preparation of oxygen using an aquatic plant

What you need

- Aquatic plants (pond weed, elodea, or any underwater plant)
- Clear container or glass bowl
- Water (preferably pond or aquarium water)
- Bright sunlight or strong lamp
- Inverted funnel or large plastic bottle with the bottom cut off
- Test tube or small jar for gas collection

What to do

1. Fill the container with water.
2. Place aquatic plants in water.
3. Invert the funnel over plants and place the test tube over the funnel spout.
4. Place in bright sunlight or under a strong lamp.
5. The time needed for the result to be observed clearly is 2-4 hours.



Expected Observation

Bubbles of a gas (oxygen) rise and collect in a test tube.

Chemical Equation

This is a biological process which produces oxygen by photosynthesis.

The chemical equation of the process is $6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$.

Activity 1.9 Test for oxygen gas

Aim: To show that oxygen supports combustion.

What you need

- Wooden splint, toothpick, or thin wooden stick
- Lighter
- Container with suspected oxygen gas
- Safety supervision

What to do

1. Light a wooden splint and let it burn for a few seconds.
2. Blow out the flame, leaving the wood glowing red-hot at the tip.
3. Quickly insert the glowing splint into the gas sample.
4. Record your observations.

Key question: What safety precautions did you observe during the activity to avoid waste, injury and damage? In your groups, write them down and discuss them. Share your thoughts with other groups.

Safety Precautions

1. Always wear safety goggles to protect the eyes.
2. Handle hydrogen peroxide with care as it can cause skin irritation and burns, especially at higher concentrations. Avoid contact with skin and eyes, and in case of contact, wash the affected area immediately with plenty of water.
3. Ensure that the apparatus is set up on a stable surface to prevent any accidental spills or breakage.
4. Avoid contact between manganese (IV) oxide and organic materials, as it is a strong oxidising agent and can cause vigorous reactions.

Activity 1.10 Compare and contrast: Physical and Chemical Characteristics of Carbon Dioxide and Oxygen Gases

Procedure

1. **Physical Characteristics**
   a. Research (or note from your experiments) the colour, odour, and state of each gas.
   b. Record similarities and differences.
2. **Chemical Characteristics**: Test effect on a burning candle: oxygen supports burning, carbon dioxide extinguishes flame.
3. **Discussion Questions**
   a. How are oxygen and carbon dioxide alike in appearance?
   b. What key chemical tests can distinguish between the two?
   c. Why are these differences important for living things and the environment?

Activity 1.11 Research task: Uses of Oxygen and Carbon Dioxide in Domestic and Industrial Settings and a Role Play of Professionals Using Oxygen and Carbon Dioxide in their Work

Objective: To investigate how oxygen (O_2) and carbon dioxide (CO_2) are used in domestic and industrial settings.

Part 1: Research uses of oxygen and carbon dioxide.

Instructions

1. Work in small groups of 4-6 people.
2. Assign one use of carbon dioxide or oxygen to each person to research. Examples:
   a. Oxygen
      i. Domestic uses (e.g., medical breathing support, fish tanks, home welding).
      ii. Industrial uses (e.g., steel production, cutting and welding metals, rocket fuels).
   b. Carbon Dioxide
      i. Domestic uses (e.g., carbonated drinks, fire extinguishers, dry ice for cooling).
      ii. Industrial uses (e.g., refrigeration, food preservation, chemical manufacturing, agriculture in greenhouses).

3. Present your research verbally to the other members of your group.

Part 2: Role Play Activity

Objective: To demonstrate how professionals use oxygen and carbon dioxide in real-life work situations.

Instructions

1. Form small groups (3–5 students).
2. Choose one profession involving oxygen or carbon dioxide, such as:
   a. **Doctor/Paramedic** – giving oxygen to a patient.
   b. **Welder** – using oxygen in metal cutting.
   c. **Food Industry Worker** – using CO_2 in soda production.
   d. **Firefighter** – using a CO_2 fire extinguisher.
   e. **Greenhouse Farmer** – using CO_2 to enhance plant growth.
3. Write a **short script (3–5 minutes)** showing how the gas is used in the job.
4. Perform the role play for the class.
5. After the role play, briefly explain the science behind the use of the gas in that profession.

EXTENDED READING

Click on the link below to a video on the test for carbon dioxide.

https://www.youtube.com/watch?v=bkiJ3xzYnY8

REVIEW QUESTIONS

1. What are the main components, and the relative amounts of these, in air?
2. How does an increase in carbon dioxide levels, reduced oxygen levels, and increased air pollution affect living organisms?
3. A chemistry teacher wants to demonstrate gas preparation to students but has limited laboratory equipment. The school only has access to household materials like baking soda, vinegar, hydrogen peroxide, fresh potatoes, and basic glassware.

    a. Analyse and evaluate the best approach for preparing both carbon dioxide and oxygen gases.

    b. Design a setup for collecting both gases that maximises safety and efficiency.

SECTION

2

OIL AND NATURAL GAS



EXPLORING MATERIALS

INTRODUCTION

Oil and natural gas are important sources of energy. They were formed millions of years ago from the remains of plants and animals buried deep under the ground. Over time, heat and pressure turned these remains into fossil fuels.

In this section, you will learn that natural gas is mostly made of methane, while crude oil contains many different substances called hydrocarbons, including alkanes. You will also find out how oil and gas are formed, taken from the ground, and used in daily life; for example, for fuel, cooking, electricity, making plastics, and fertilisers.

KEY IDEAS

- Benefits of crude oil and natural gas.
- Composition of crude oil.
- Difference in composition of crude oil and natural gas.
- Environmental impacts of crude oil and natural gas.
- Extraction of the components of crude oil.

COMPOSITION AND USES OF OIL AND NATURAL GAS

Dear learner, you are welcome to yet another exciting week. Guess what? Let's call this week a week of "black gold." Make no mistake, gold cannot be black. This is only a jargon which refers to crude oil and natural gas. You may have heard of rich countries associated with petroleum and natural gas. What is their success story, and why do crude oil and natural gas enrich them? Let us find out about "black gold."

Crude Oil Composition

Crude oil is a naturally occurring, unrefined liquid petroleum, a mixture of hydrocarbons (compounds made mainly of hydrogen and carbon) that is found accumulated underground in the earth's crust. Various types of crude oils with different properties are available in the market. Its price depends upon density as well as the presence of sulphur, metals, and other contaminants present in it. The composition of crude oil varies with the geographical location, age, and depth of the well.

The composition of crude oil can be categorised based on the presence of elements, molecules, and compounds present in it. Basically, crude oil is composed of;

1. Hydrocarbon compounds
2. Non-hydrocarbon compounds
3. Inorganic substances.

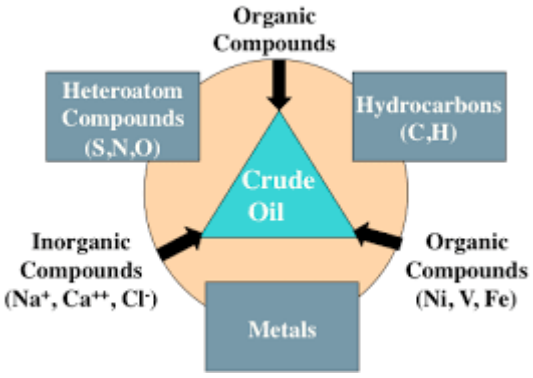




Figure 2.1: Crude oil

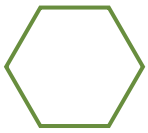
Hydrocarbons

These include alkanes (paraffins), cycloalkanes, aromatic hydrocarbons (arenes) and asphaltenes.

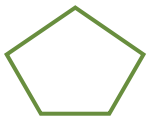
1. **Alkanes (Paraffins):** Alkanes, also called paraffins, are saturated hydrocarbons which contain only single bonds between carbon atoms. They have the general chemical formula, C_nH_{2n+2}. They can form straight-chain compounds (normal alkanes) or branched-chain ones (iso-alkanes).

   Examples of alkanes include methane (CH_4), ethane (C_2H_6), propane (C_3H_8), and butane (C_4H_{10}). Heavier alkanes are found in substances like gasoline, kerosene, and lubricating oils. Of all hydrocarbons, paraffins are usually the most abundant in crude oil.

2. **Cycloalkanes (Naphthenes or Cycloparaffins):** Cycloalkanes are also known as naphthene. They are saturated hydrocarbons which have ring structures. Their general formula is C_nH_{2n}. Examples include cyclopentane and cyclohexane. These compounds are important parts of gasoline and other products from petroleum refineries. Like alkanes, they are also saturated, but their ring structure gives them different chemical properties.



cyclohexane



cyclopentane

3. **Aromatic Hydrocarbons (Arenes):** Aromatic hydrocarbons, or arenes, contain one or more benzene rings. A benzene ring is a structure made of six carbon atoms with alternating double bonds. The simplest example is benzene (C_6H_6). Others are toluene, xylene, and more complex compounds known as polycyclic aromatic hydrocarbons (PAHs). Aromatic compounds are valued for their role in increasing gasoline's octane rating. They are also used as starting materials in the chemical industry.



benzene



1,4-dimethylbenzene (para-xylene

4. **Asphaltenes:** These are large and complex hydrocarbon molecules. They often contain atoms such as nitrogen, sulphur, and oxygen, along with small amounts of metals like vanadium and nickel. Unlike lighter hydrocarbons, asphaltenes are insoluble in low-boiling liquids like propane or butane, but soluble in carbon disulphide. They increase the density and thickness (viscosity) of crude oil and are common in bitumen and heavy oils.

Non-Hydrocarbon Compounds

Crude oil also contains organic compounds that are composed of elements other than carbon and hydrogen. They include sulphur compounds, nitrogen compounds, oxygen compounds and organometallic compounds.

These are heteroatoms which can significantly impact the properties and refining processes of crude oil.

1. **Sulphur compounds**: They range from simple hydrogen sulphide (H_2S) to more complex organic sulphur compounds such as mercaptans (thiols), sulphides, disulfides, and thiophenes. Sulphur content is a key factor in crude oil quality. "Sweet crude" has low sulphur content, while "sour crude" has high sulphur content. High sulphur content can lead to corrosion and environmental issues during refining and combustion processes of crude oil.

2. **Nitrogen compounds:** These are basic or neutral organic compounds which contain nitrogen atoms within their molecular structures. Examples are pyridines, quinolines and porphyrins. Nitrogen compounds can poison catalysts used in refining processes.
3. **Oxygen compounds:** These include organic acids (naphthenic acids), phenols, ketones, ethers, and esters. Presence of organic acids in crude oil can contribute to corrosion.
4. **Organometallic compounds:** These contain metal atoms (like nickel and vanadium) chemically bonded to organic molecules, often associated with porphyrin structures. They can cause catalyst deactivation during refining and contribute to deposits.

Inorganic components

Crude oil also contains trace amounts of dissolved inorganic salts (e.g., chlorides of sodium, calcium, and magnesium) and water. These need to be removed during processing to prevent corrosion and damage of equipment.

Natural Gas

Natural gas is a naturally occurring gaseous hydrocarbon mixture which consists primarily of lighter alkanes. Its composition is generally simpler than that of crude oil. it is an important source of energy used in many parts of our daily lives.

Natural gas is cleaner than other fossil fuels like coal and oil, and it plays a big role in Ghana's electricity supply, cooking, industry, and transport.

Composition of Natural Gas (by Volume)

1. **Methane (CH_4):** Is the dominant component, ranging from 70% to 99%.
2. **Ethane (C_2H_6):** Is usually present in smaller amounts than methane.
3. **Propane (C_3H_8) and Butane (C_4H_{10}):** These are often present in varying, but generally lower, concentrations. When natural gas is rich in propane and butane, it is sometimes referred to as "wet gas."
4. **Pentanes (C_5H_{12}) and heavier hydrocarbons:** These may be present in trace amounts. It may condense out as natural gas liquids (NGLs) under certain conditions.

Non-hydrocarbon gases

Natural gas often contains varying amounts of other gases which are not hydrocarbons.

These are:

1. **Carbon dioxide (CO_2):** It can range from trace amounts to significant percentages. It needs to be removed as it reduces the heating value of natural gas and can cause corrosion.
2. **Nitrogen (N_2):** Is another common non-hydrocarbon component that dilutes natural gas and reduces its heating value.

3. **Hydrogen sulphide (H_2S):** Is a toxic and corrosive gas that must be removed. Its presence makes the gas "sour" or unusable. To make it usable, the "sour" gas undergoes a "gas sweetening" process to remove H_2S and CO_2, producing "sweet gas."
4. **Water vapor (H_2O):** Needs to be removed to prevent corrosion and hydrate formation in pipelines.
5. **Helium (He):** In some specific locations, natural gas can contain commercially viable amounts of helium.
6. Other trace gases like argon (Ar).

Differences Between Natural Gas And Crude Oil In Composition

1. **State at surface conditions:** Crude oil is liquid at standard temperature and pressure, while natural gas is gaseous.
2. **Molecular weight:** Crude oil contains a much wider range of hydrocarbon molecules, including very heavy and complex ones, while natural gas is dominated by light, low molecular weight hydrocarbons.
3. **Non-Hydrocarbon content:** Both contain non-hydrocarbons, but the types and proportions can differ. For instance, natural gas can have significant amounts of non-combustible gases like CO_2 and N_2.

Economic Benefits of Oil and Gas in Ghana

1. **Source of income (Money)**: The oil and gas industry give the Ghanaian government a lot of money. This comes from taxes, fees (called royalties), and the government's share in oil projects. This money helps Ghana pay for schools, roads, hospitals, and other important national projects. Experts say Ghana could earn up to $21 billion from oil and gas between 2015 and 2030.
2. **Growth of the economy (GDP)**: When Ghana started selling oil in 2011, the economy grew very fast. This helped make Ghana one of the fastest-growing countries in Africa at that time. When Ghana earns more money from oil, the economy improves.
3. **More products to export**: Before oil, Ghana mostly exported gold and cocoa. Now, Ghana also exports oil, which gives the country more ways to earn money from other countries.
4. **Earning foreign currency**: Selling oil to other countries helps Ghana earn foreign money (like US dollars), which is needed for buying goods from other countries and keeping the Ghana cedi stable.
5. **Creating jobs**: The oil and gas industry gives jobs to many Ghanaians. People work in oil drilling, transportation, security, and support services.
6. **Improving roads and buildings (Infrastructure)**: Some of the money from oil is used to build roads, schools, electricity lines, and water systems. This makes life better and helps businesses work more efficiently.
7. **Bringing in investors**: Because Ghana has oil and gas, many international companies are coming to invest. These companies bring money, machines, and skilled workers, which help grow the economy. The government is also making the industry fair and open so more investors will feel safe doing business in Ghana.

How Oil And Gas Are Changing Ghana's Energy Sector

1. **Making electricity (Power generation):** Ghana uses natural gas from oil production to make electricity. This is better than relying only on water (hydropower) or expensive fuels like diesel. Gas makes electricity more reliable and may cost less in the future.
2. **Helping factories work better (Industrial growth):** Some factories get natural gas at lower prices (subsidies), which helps them save money and work more efficiently. These include factories that make fertiliser, ceramics, and petrochemicals. In the future, even more factories, like those in mining, may also use gas.
3. **LPG for cooking and business:** Natural gas is used to make LPG (Liquefied Petroleum Gas). This is used in homes and businesses for cooking. The government wants more people to use LPG because it is cleaner and safer than wood or charcoal.

Impact of oil and gas discoveries in Ghana

1. Environmental damage

Damage	Causes	Impact
Oil spills	This is as a result of accidents caused during drilling, transportation (tanker accidents), or pipeline leaks.	1. Devastate marine ecosystems, harming or killing fish, seabirds, marine mammals, and coastal vegetation. 2. Pollute beaches and coastal areas, affecting tourism and fishing industries. 3. Long-term damage to ecosystems, as oil can persist in sediments for years.
Water pollution	1. Wastewater discharge from drilling operations, containing drilling fluids, heavy metals, and other pollutants. 2. Contamination of groundwater from fracking operations (if applicable).	1. Harm aquatic life. 2. Make water unsuitable for drinking or agriculture. 3. Damage local ecosystems.
Air pollution	1. Emissions from drilling rigs, refineries, and associated transportation. 2. Release of methane (a potent greenhouse gas) during extraction and processing. 3. Flaring of natural gas (burning off excess gas), which releases pollutants.	1. Contribute to respiratory problems and other health issues. 2. Worsen air quality. 3. Contribute to climate change.

Habitat destruction	1. Construction of drilling platforms, pipelines, roads, and other infrastructure. 2. Deforestation and land clearing.	1. Destroy natural habitats, displacing wildlife. 2. Fragment ecosystems, reducing biodiversity. 3. Damage coastal ecosystems like mangroves, which are important for fisheries and coastal protection.



Figure 2.2: Crude oil spillage destroys aquatic life

2. Social Impacts

Crude oil in Ghana has generated mixed social impacts, balancing national economic growth with significant local disruptions. While creating jobs, contributing over billion in revenue since 2011, and fostering infrastructure in host communities, it has also caused some negative impacts. In some communities, the discovery of oil and gas has made the cost of living (like food and housing) more expensive and strained fishing livelihoods. It can also lead to social problems such as crime, unsafe behaviours, and conflicts among people.

3. Revenue Management

The money Ghana earns from oil and gas must be used properly and shared fairly. If the money is wasted or misused, it can lead to what is called the "resource curse", where a country becomes poor even though it has valuable resources.

Good planning helps the country grow and develop in the long term.

Uses of Natural Gas

1. **Producing electricity:** In power plants, natural gas is burned to produce steam, which turns turbines to generate electricity. Natural gas produces less pollution than coal or oil, which helps protect the environment. It is also more flexible, as gas power plants can be turned on or off quickly depending on how much electricity is needed. In Ghana, natural gas helps provide power for homes and industries.
2. **Natural gas is also used for heating:** It is also used in industries that need high temperatures for making products. It is cleaner, cheaper and more efficient source of heat.

3. **In cooking**: Natural gas gives a strong and clean flame, which makes cooking easier and faster. Many people and restaurants prefer gas stoves because they can control the heat well. In Ghana, LPG is the most common gas used for cooking in homes. It is safe, easy to use, and widely available in cylinders.
4. **In factories and industries, natural gas is used as a raw material to make products**: Naturals gas helps make fertilisers, which are important for farming. It also helps in producing chemicals like methanol and ammonia, and hydrogen used in fuel and refining processes. Using natural gas in industry can help Ghana create jobs, produce more goods locally, and grow its economy.
5. **Natural gas can also be used in transportation:** Compressed Natural Gas (CNG) is a type of fuel used in vehicles like buses and taxis. It is cleaner and eco-friendly than petrol and diesel, and it helps reduce air pollution. It is composed primarily of methane and created by compressing natural gas to less than 1% of its atmospheric volume.

Key questions: What are the various processes involved in the separation of crude oil into its component fractions for use?

Processes Involved In Extraction Of Oil And Gas

The extraction of oil and gas involves several important steps. Each stage is necessary to safely bring these resources from deep underground to the surface where they can be used. The process includes exploration, drilling, well completion, and production.

1. **Exploration:** The first step is exploration, which focuses on finding underground areas that may contain oil or gas. Scientists begin by using seismic surveys, where sound waves are sent into the ground and their echoes are recorded. These echoes help create images of the earth's layers, which geologists study to spot places where oil or gas might be trapped.
2. **Exploratory drilling:** If the images from the seismic surveys look promising, the next step is exploratory drilling. A test well is drilled to check if oil or gas is really there. This helps experts learn about the size, depth, and quality of the reservoir. This part of the process is expensive and risky because there is no guarantee that oil or gas will be found.
3. **Drilling:** Once oil or gas is found, the next step is drilling a deeper and proper well to reach the reservoir. A drilling rig, which is a large machine, is used to make a hole in the ground. At the end of a long pipe, there is a drill bit, a strong cutting tool that breaks through rocks. During drilling, a special liquid called drilling mud is pumped down to cool the drill bit, bring up crushed rock, and keep the well stable. In many cases, directional drilling is used to drill at an angle or even horizontally. This method helps reach more oil or gas with fewer wells. In Ghana, both land-based (onshore) and sea-based (offshore) drilling operations take place. These require skilled workers and advanced equipment.
4. **Well completion:** After the drilling is done, the well must be prepared to safely extract oil or gas. This step is called well completion. Steel pipes known as casings are put

into the well and cemented in place. This makes the well strong and prevents oil, gas, or water from leaking.

5. **Perforation:** Perforation is a well-completion process that creates tunnels through the steel casing, cement, and into the target rock formation using explosive-shaped charges. This establishes a vital conduit for oil and gas to flow from the reservoir into the wellbore. It is generally performed after the well is drilled and cased. In some cases, a process called hydraulic fracturing (fracking) is used. This involves pumping or injecting fluid at high pressure into the rock to create cracks. These cracks make it easier for the oil or gas to flow.
6. **Production:** The final stage is production, where oil and gas are brought to the surface. In the beginning, the natural pressure inside the reservoir is enough to push the oil or gas out. This is called primary recovery. But as pressure drops, less oil comes out.

   To get more oil, secondary recovery is used. Water or gas is pumped into the reservoir to push the oil or gas towards the well. In difficult cases, enhanced oil recovery (EOR) methods are used. These include injecting heat, gas, or chemicals to make the oil flow more easily. Ghana uses different methods depending on the type of reservoir, aiming to get as much oil or gas out as possible.
7. **Transportation:** Once extracted, oil and gas must be transported from the production site to refineries, processing plants, and consumers.

   Pipelines: These are the most common and efficient way to transport large volumes of oil and gas over long distances, both onshore and offshore.

   Tankers: Ships are used to transport oil and liquefied natural gas (LNG) across oceans. LNG is natural gas that has been cooled to a liquid state to reduce its volume for transportation. Tank trucks are used to transport smaller volumes of oil and gas over shorter distances. Ghana utilises pipelines to transport oil and gas within the country and tankers for exporting oil to international markets.
8. **Processing:** Raw oil and gas need to be processed to make them usable. Crude oil is refined in refineries to separate it into various petroleum products, such as gasoline, diesel fuel, jet fuel, heating oil, and asphalt. Natural gas is processed to remove impurities such as water vapour, carbon dioxide, hydrogen sulphide, and other gases. It may also be separated into its components, such as methane (the main component of natural gas), ethane, propane, and butane. Ghana has refineries such as Tema Oil Refinery to process crude oil and gas processing plants to prepare natural gas for distribution and use in the country.

Hydraulic fracturing (Fracking)

Fracking is a special method used to get oil and natural gas out of rocks that are very hard and do not let fluids flow through them easily. Think of it like trying to get juice out of a very tight sponge - you need to create cracks to let the juice flow out.

How does fracking work? (Step-by-step process)

Step 1: Drilling the well

Fracking begins with drilling a deep hole from the surface of the ground down to a rock layer that contains oil or natural gas. This hole can be drilled straight down (vertical drilling) or sideways underground (horizontal drilling). Horizontal drilling is often preferred because it allows access to more of the oil- or gas-rich rock. This step is important because it creates a pathway to reach the oil and gas trapped deep underground. It is like inserting a straw into a bottle to reach the liquid at the bottom.

Step 2: Strengthening the well (Casing and cementing)

After drilling, steel pipes known as *casings* are placed inside the hole to keep it strong and stable. Then, cement is poured around the casing to seal the well. This prevents the well from collapsing and stops harmful substances from leaking into underground water supplies used for drinking. This step also ensures that the oil and gas will flow through the correct path. It can be compared to placing a strong pipe inside a wall and sealing it with concrete to prevent leaks.

Step 3: Injecting fracturing fluid

Next, a mixture of water, sand, and chemicals (e.g., hydrochloric acid, acetic acid and isopropanol) is pumped into the well at very high pressure. This pressure causes the surrounding rock to crack, creating small pathways for the oil and gas to move through. The fluid mixture usually contains about 90% water, sand to keep the cracks open, and a small amount of chemicals. These chemicals serve different purposes: reducing friction, thickening the fluid, killing bacteria, and protecting the metal pipes from rust. This process is similar to using a high-pressure hose to break ice, then placing small objects into the cracks to keep them open.

Step 4: Keeping cracks open with sand (Proppants)

The sand particles, also called proppants, are carried by the fluid into the cracks in the rock. When the pressure is removed, the sand stays inside the cracks and keeps them open. This allows oil and gas to continue flowing through the cracks. Without the sand, the cracks would close again, like how a sponge closes after being squeezed. You can think of this as putting tiny pebbles in a door crack to keep it from closing.

Step 5: Oil and gas production

In the final step, the pressure inside the well is gradually reduced. This allows oil and gas to begin flowing up the well to the surface. Some of the water mixture also returns to the surface. This is called *flowback water*. Along with the oil and gas, substances such as salts, minerals from the rocks, and sometimes naturally occurring radioactive materials may also come up. It is very important that the used water is properly handled and treated to avoid environmental pollution.

Importance of fracking

1. **Accessing Oil and Gas from Hard-to-Reach Rocks**: Before the introduction of fracking, oil and gas trapped deep inside tight rock formations could not be extracted. Fracking has made it possible to break open these rocks, allowing the oil and gas to flow out. This process has significantly increased the availability of oil and gas around the world.
2. **Getting more from each well**: Fracking not only helps in accessing difficult-to-reach resources but also improves the performance of oil and gas wells. It allows each well to produce more oil and gas over a longer period of time. As a result, companies get better returns from their drilling efforts, making the entire process more efficient and profitable.
3. **Increasing energy independence**: Through fracking, countries can produce more of their own oil and gas. This reduces the need to import energy from other nations and makes a country less affected by global price changes. Producing energy locally also strengthens national security and supports stable energy supplies.
4. **Creating jobs and supporting the economy:** Fracking supports job creation in several areas. Workers are needed for drilling, transporting materials, operating equipment, and providing other support services. As more people are employed, income increases in communities, and local economies benefit through increased spending and development.

Activity 2.1 Oil refining simulation

Aim: To understand how crude oil is separated into different products through fractional distillation

What you need

- Cooking oil (vegetable oil)
- Water
- Food colouring (red, blue, yellow, green)
- Clear plastic bottles (5-6 different sizes)
- Measuring cups
- Funnel
- Labels and markers
- Thermometer (if available)
- Hot water from the kitchen
- Ice cubes

What to do

1. **Mix the crude oil simulation**

a. 200ml cooking oil
b. 50ml water
c. Add different food colourings to represent different hydrocarbons:
    - Red drops represent Heavy fuel oil
    - Blue drops represent Diesel
    - Yellow drops represent Kerosene
    - Green drops represent Petrol/gasoline
d. Shake well to create your "crude oil" mixture

2. **Temperature-based separation**
    a. Cold separation (simulating light fractions)
        i. Pour the mixture into a clear bottle
        ii. Add ice cubes around the bottle
        iii. Wait 10 minutes and observe layers forming
        iv. Record: Which colours separate first?
    b. Warm separation (simulating heavy fractions)
        i. Warm another portion in a hot water bath
        ii. Observe how heating affects the mixture
        iii. Record: How does temperature change the separation?
        Write down your response and share it with your friends.

3. Density separation
a. Create density tower
    i. In a tall, clear container, slowly layer
        - Bottom: Coloured water (heaviest - represents heavy fuel oil)
        - Middle: Thick oil mixture (represents diesel/kerosene)
        - Top: Light oil (represents petrol)
    b. Observe and record
        i. Which products settle at different levels?
        ii. How does this relate to real oil refining?

Write down your response in your notebook and share it with your friends.

Activity 2.2 Debate on Crude Oil

Perform this activity in a group of ten members.

Aim: To develop an evidence-based argument on the usefulness and economic necessity of oil and gas discovery in Ghana, using economic data, policy reports, and examples from oil-producing regions.

What to do: Watch a video from the following link: https://youtu.be/kYeHOi2wb8U

Use information from the video and from earlier in these learning materials to produce a one-page mind-map or poster summarising the use, necessity and impact of crude oil and natural gas use in Ghana.

Then, form small groups of 3-5 people. Share ideas and draw conclusions of the impact of the oil find on Ghana's economy and the way forward; facilitate healthy debate. Do any of you completely oppose the burning of fossil fuels in Ghana? Conversely, are any of you very pro- fossil fuels? Compare points of view and respect one another's standpoints.

Activity 2.3 Create a flowchart of the oil refinery process

Use the information above, as well as any other available resources (the internet or textbooks), to produce a short flow diagram of the oil refinery process. Include brief descriptions of what happens at each step.

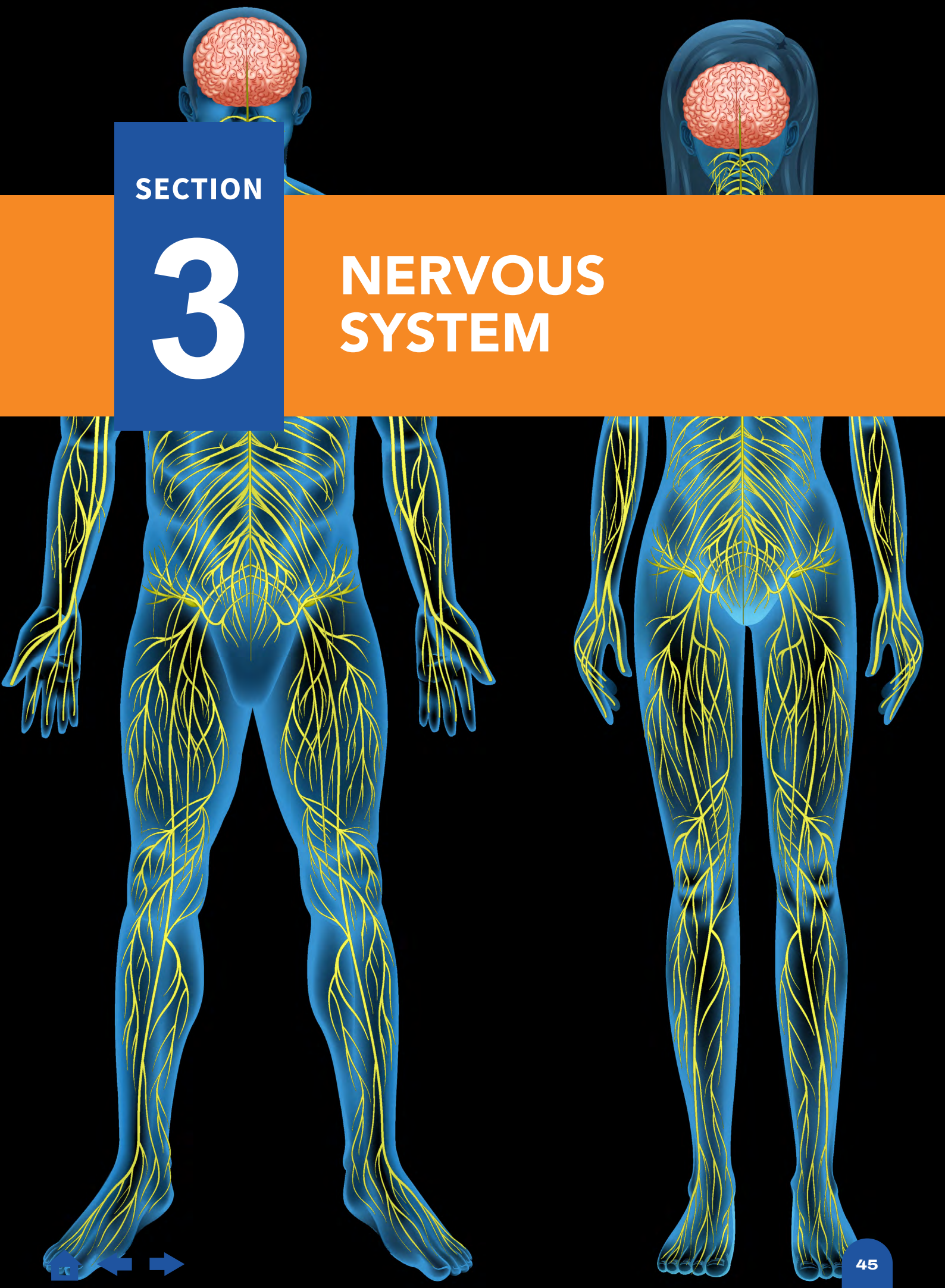
See Annex 2.0 on page xxxx for an example solution

EXTENDED READING

- https://www.youtube.com/watch?v=CjmriZq5xRo
- https://www.researchgate.net/publication/259139029/figure/fig1/AS:586921000579072@1516944279569/Simplified-flow-chart-of-crude-oil-refinery-processes.png
- https://thumbs.dreamstime.com/b/crude-oil-surface-textured-background-67505768.jpg

REVIEW QUESTIONS

1. List the four main types of hydrocarbons found in crude oil.
2. Analyse three environmental impacts of oil and gas extraction and explain their causes.
3. Ghana is developing a 20-year energy strategy that balances economic growth, energy security, and environmental protection. As an energy consultant, design a comprehensive plan that optimises the use of Ghana's oil and gas resources while transitioning toward renewable energy.



SECTION

3

NERVOUS SYSTEM

PROCESSES FOR LIVING

INTRODUCTION

The human nervous system is a very important part of the body that helps us think, move, feel, and react to things around us. It works like a control centre, sending and receiving messages throughout the body. In this topic, you will learn about the two main parts of the nervous system which are the central nervous system (CNS) and the peripheral nervous system (PNS). The central nervous system is made up of the brain and spinal cord while the peripheral nervous system links the rest of the body to the brain and spinal cord. You will also explore how some body actions happen automatically, like breathing and heartbeat, through another part called the autonomic nervous system. Finally, you will understand how messages travel through the body using special cells called neurons.

KEY IDEAS

- **Autonomic Nervous System:** Controls involuntary actions like heartbeat and breathing.
- **Brain:** Processes information and sends instructions. It acts as the command centre for the central nervous system
- **CNS:** Made up of the brain and spinal cord; controls most body functions.
- **Nerve impulses:** Electrical signals that carry messages through neurons.
- **PNS:** Links the CNS to the rest of the body through nerves.
- **Spinal Cord:** Sends messages between brain and body, controls reflexes.

CONCEPTS OF THE NERVOUS SYSTEM AND THE CNS

The nervous system controls your actions. It is made up of neurons or nerve cells, coordinating different parts of your body so that they can work together and be able to bring about the correct responses.

The nervous system is commonly divided into two parts: the central nervous system (CNS) and the peripheral nervous system (PNS).

Meaning of Nervous system

The nervous system is like the body's control centre and messaging system which helps us to think, move, feel things and even do things we are not aware or curious of, like breathing and blinking of the eye. The system is made up of two main parts;

1. The Central Nervous system CNS) and
2. The Peripheral Nervous system. (PNS)

The Central Nervous System (CNS)

The central nervous system (CNS) consists of the brain and the spinal cord acting as the main processing centre for information.

The brain tissue is protected by the bony skull, and the spinal cord is protected by the backbone or the vertebrae. Nerves link the brain and spinal cord to the rest of the body. The spinal cord and the brain consist of white and grey matter.

In the spinal cord, the white matter is at the surface with the grey matter inside, but this pattern is reversed in the brain of mammals, the grey matter lying on the outer surface, while white matter lies beneath it.

Components of Central nervous System (CNS) and their functions

The Brain

The brain is the body's most complex organ, weighing about 3 pounds and controlling vital functions (breathing, heart rate), sensory processing, emotions, and cognition. It acts as the command centre for the central nervous system, utilizing billions of neurons to regulate, think, and store memories. The brain must be healthy for the body to work properly. The outer surface of the cerebrum (the largest part of the brain) is called the cerebral cortex, and it is made of grey matter, which contains nerve cell bodies and fibres that help send and receive messages. Inside the cerebrum, is white matter, which is made of fibres covered with a protective layer called myelin. These fibres help carry messages quickly between parts of the brain.

The main parts of the brain are the

1. Forebrain (Cerebrum)
2. Midbrain
3. Hindbrain (Cerebellum)
4. Medulla Oblongata

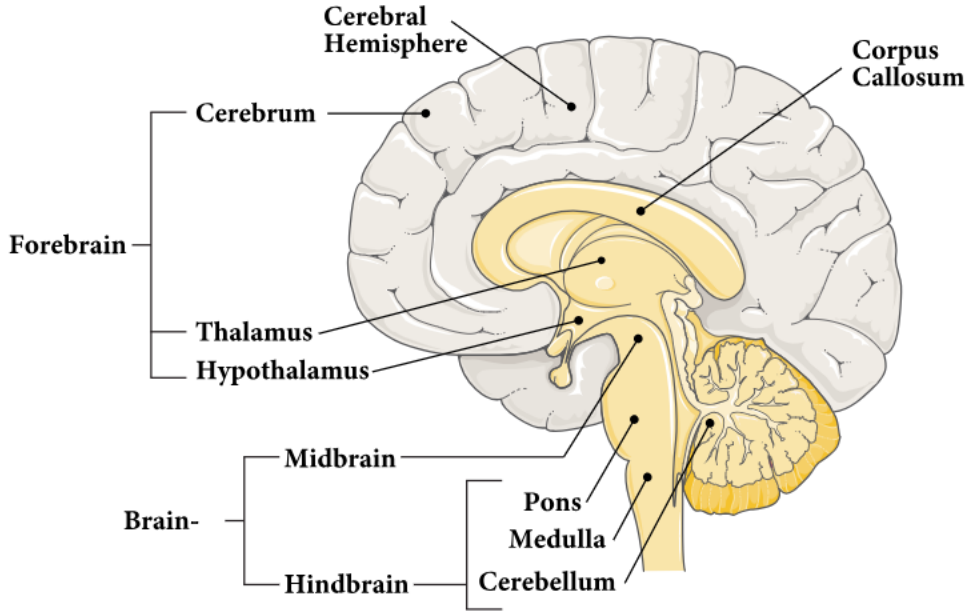


Figure 3.1: A diagram of the human brain

1. Cerebrum (Forebrain)

The cerebrum is the largest part of the human brain, and it is divided into two halves called the left and right cerebral hemispheres. These hemispheres are separated by a deep groove known as a fissure. Each hemisphere is further divided into four main lobes that can be seen from the outside: the frontal lobe, the parietal lobe, the occipital lobe, and the temporal lobe.

Functions of the Cerebral cortex or Cerebrum

a. The cerebrum helps us learn new things and store information.
b. It allows us to use intelligence and solve problems.
c. It interprets sensory information, such as what we see, hear, feel, taste, and smell.
d. It controls voluntary movements of our muscles.
e. It is responsible for thinking, imagination, and reasoning.
f. It stores memories and controls emotions.
g. It helps us develop new skills and coordinate body movements.
h. It plays a role in shaping our personality.
i. It controls important functions like speech, vision, taste, smell, and touch.

The cerebrum also has other important parts that help control different body functions and mental processes.

A. Hypothalamus
B. Pituitary gland

A. Hypothalamus: The hypothalamus is a small but very important part of the brain located just below the thalamus. It controls many body functions by producing hormones and directing the pituitary gland to maintain homeostasis (internal stability).

Functions of the Hypothalamus

i. Helps the body keep the right balance of water and salts.
ii. Checks the level of carbon dioxide in the blood.
iii. Controls and maintains normal body temperature.
iv. Regulates when we sleep and wake up.
v. Controls hunger, thirst, and body weight.
vi. Helps to control heart rate and blood pressure.

B. Pituitary Gland: The pituitary gland, also called the "master gland," is found at the base of the brain just below the hypothalamus. It produces hormones that regulate many body functions and also control other endocrine glands.

Functions of pituitary hormones

i. Help the body grow physically.
ii. Regulate the balance of water in the body.
iii. Stimulate and control the activities of other endocrine glands.
iv. Control sexual development and metabolism.

2. Midbrain

The midbrain is a small part of the brain found between the forebrain and the hindbrain. It contains nerve fibres covered with myelin and centres for visual and hearing reflexes.

Functions of the midbrain

1. Controls eye movement.
2. Coordinates head movement in response to light and sound.
3. Processes sound information.

3. Hindbrain

The hindbrain is made up of the cerebellum and the medulla oblongata. It acts as the command centre for essential survival functions (acting as the body's autopilot)

A. Cerebellum: Also referred to as "little brain" the cerebellum receives information from the inner ear and muscles to help the body stay balanced and maintain posture. Drinking too much alcohol can disturb its function.

Functions of the cerebellum

i. Maintains posture and balance.
ii. Coordinates voluntary movements such as walking, running, or driving.
iii. Helps to maintain normal muscle tone.

B. Medulla Oblongata: The medulla oblongata lies below the cerebellum and connects the brain to the spinal cord. It controls many involuntary activities of the body.

Functions of the medulla oblongata

i. Controls heart rate and breathing.
ii. Regulates blood pressure.
iii. Manages reflexes such as coughing, sneezing and yawning.
iv. Controls swallowing and vomiting.

Functions of the Central Nervous System (CNS)

1. Controls human emotional behaviour.
2. Manages all reflex and conditioned reflex actions.
3. Coordinates the body's response to changes in the environment (e.g., regulating body temperature when external temperature changes).
4. Receives information from all parts of the body through sensory neurons, interprets it, and sends the correct response through motor neurons to effectors such as muscles and glands.

Causes of Failure of the Nervous System (Brain and Spinal Cord)

1. **Psychological conditions (e.g., depression):** Mental health problems such as depression and anxiety can change brain structure and function. Stress and depression may reduce neurotransmitter levels, shrink brain areas like the hippocampus (important for memory), and affect thinking. Long-term stress may also increase the risk of brain diseases such as Alzheimer's.
2. **Substance abuse (e.g., Indian hemp, heroin):** Drugs and alcohol can damage the brain. Prolonged use of substances like marijuana, heroin, cocaine, and methamphetamine changes how the brain works, affecting memory, thinking, and self-control. Some drugs lower oxygen supply to the brain, killing cells and increasing the risk of strokes. Alcohol abuse may cause Wernicke-Korsakoff syndrome, a brain disorder linked to vitamin B1 deficiency.

3. **Mental Illness and Sexually Transmitted Infections (STIs)**
   a. Disease that gets worse over time. The brain or nerves are being damaged slowly by some disease over time. For a example Alzheimer's disease, this cause memory loss, Parkinson disease affects movement, multiple sclerosis affects how nerves send signals.
   b. Tumours, an outgrowth of cell into a lump. This in the brain or spinal cord can press vital organs and stop them from working well
   c. Additionally, sexually transmitted infections (STIs) such as syphilis and HIV can damage the nervous system. Neurosyphilis affects the brain and spinal cord, leading to cognitive decline and movement disorders. HIV-associated neurocognitive disorders (HAND) occur when the virus damages brain cells, leading to difficulties in memory, concentration, and coordination.

4. **Physical trauma (e.g., Motor vehicle and domestic accidents):** Traumatic injuries from accidents or physical abuse can cause permanent damage to the brain and spinal cord. A traumatic brain injury (TBI) may result from falls, blows to the head, or car accidents, leading to loss of cognitive function, impaired speech, and personality changes. Spinal cord injuries from severe impacts can result in paralysis, loss of sensation, and difficulty in motor function. The severity of these injuries often depends on the location and extent of the damage.

The Spinal Cord

The spinal cord is a soft, white, rope-like structure that runs inside the backbone. It begins from the medulla oblongata in the brain and extends through the length of the vertebral column. The backbone protects the spinal cord from injury. At its centre, the spinal cord has a canal called the central canal, which is filled with cerebrospinal fluid.

The spinal cord has two main parts: the inner grey matter and the outer white matter. The grey matter contains nerve cells (neurons) and surrounds the central canal, giving it a grey colour. The white matter contains nerve fibres, which give it a whitish appearance.

On the surface of the spinal cord, there are two grooves: one at the back called the dorsal fissure, and one at the front called the ventral fissure.

The spinal cord has 31 pairs of spinal nerves connected to it. The sensory nerves enter the spinal cord through the dorsal (back) roots, carrying information like touch, heat, and pain towards the brain. The motor nerves leave the spinal cord through the ventral (front) roots, carrying instructions from the brain to the muscles and glands.

In addition, there are side parts of the spinal cord called the lateral columns, which carry both sensory and motor information. These are called mixed nerves.

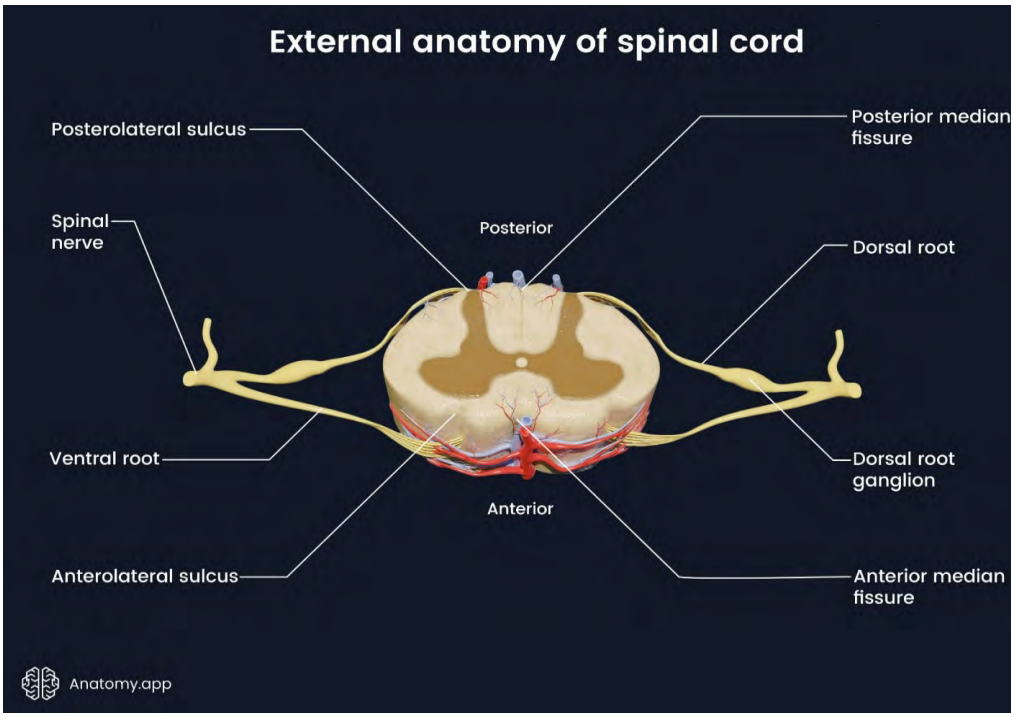


Figure 3.2: A diagram of the spinal cord.

Functions of the Spinal Cord

The spinal cord serves as a vital communication and coordination centre within the central nervous system.

1. The spinal cord receives information from different parts of the body through sensory nerves. These nerves carry messages about things like pain, heat, pressure, or touch into the back part of the spinal cord. From there, the information is sent to the brain so it can be understood.
2. The spinal cord also sends instructions from the brain to the body. Motor nerves carry these messages from the front part of the spinal cord to muscles and glands. This allows the body to move or for glands to release substances.
3. The spinal cord controls reflex actions. Reflexes are quick, automatic responses to stimuli, and do not need the brain's help. For example, when you touch something hot, your hand pulls away immediately. This fast response helps to protect the body from harm.

In a group of at least 5 members. Write down your findings on what happened when you get an itch on your elbow.

Activity 3.1 Transmission of Nerve Impulses

What to do

Study the following step-by-step description of how the body responds to an itchy elbow, and then answer the questions that follow

1. Receptors in your skin detect an itch on your right elbow
2. The receptors send a message along sensory neurons to the spinal cord
3. The message is sent up to the brain, telling it what is happening
4. The brain receives a message about the itchy skin
5. The brain decides to scratch your elbow with your left hand, it sends a message back down the spinal cord
6. The message is sent to the muscle in your hand and arm from the central nervous system down the motor neuron
7. The muscle moves your hand and arm to scratch the itchy skin.

Key questions

1. Identify the stimulus in the reaction.
2. What is the response?
3. Which part of the body is the receptor, the effector, and the coordinator?

Activity 3.2 Building your personal CNS model

Aim: Create a model of your nervous system to understand its structure and functions

What you need

- Three different coloured modelling clay or playdough
- Cardboard base (size of a book)
- Toothpicks and small labels
- Measuring tape or ruler
- Mirror
- Notebook for observation

What to do

Step 1: Build your Cerebrum

1. Take pink/red clay and form a large oval shape (about 8cm long)
2. Draw a line down the middle; this separates the left and right hemispheres
3. Mark the four lobes with toothpicks
    a. Frontal lobe (front): Where you think and plan
    b. Parietal lobe (top): Where you feel touch
    c. Temporal lobe (sides): Where you hear and remember
    d. Occipital lobe (back): Where you process vision

Self-Test: Point to each lobe on your model and explain what it does.

a. **Build your cerebellum**
    i. Take yellow clay and make a smaller round shape (3cm diameter)
    ii. Add ridges with a pencil to show it is folded
    iii. Place behind your cerebrum
    iv. Label: “Balance and coordination”

Stand on one foot while looking at your model. Your cerebellum is working to keep you balanced!

b. **Build your brain stem**
    i. Take brown clay and make a cylinder (4cm long, 2cm wide)
    ii. Connect to the bottom of the cerebrum
    iii. Label three parts
        - Midbrain (top): Eye movement
        - Pons (middle): Sleep regulation
        - Medulla oblongata (bottom): Breathing and heart rate

Self-Test: Count your heartbeats for 15 seconds. Your medulla oblongata controls this automatically.

Step 2: Build your spinal cord

1. Take the remaining brown clay and roll it into a long rope (12cm)
2. Attach to the bottom of the brain stem
3. Make small marks every 2cm to show segments
4. Add small clay pieces sticking out - these are nerve branches.

Self-Test: Feel along your spine from neck to lower back. This is where your spinal cord runs.

Step 3: Test CNS functions

Cerebrum tests

1. Frontal lobe: Solve this math problem: 25 + 17 =?
2. Parietal lobe: Close your eyes and touch your nose
3. Temporal lobe: Listen to sounds around you for 30 seconds
4. Occipital lobe: Look at your model and identify the colours

Cerebellum tests:

1. Walk in a straight line heel-to-toe for 10 steps
2. Touch your nose with alternating hands (eyes closed)
3. Stand on one foot for 30 seconds

Activity 3.3 Exploring functions of CNS

Aim: To get familiarised with the functions of the central nervous system.

What to do

1. In a group of 6 (3 pairs), conduct research into functions of different parts of the central nervous system, e.g.
   a. The cerebral cortex in cognition
   b. The spinal cord in reflexes
   c. The brainstem in the regulation of vital functions
2. Discuss your findings as a group and with members of other groups.
3. Using your findings as a prompt, conduct a role-play scenario whereby each of the group members represents a different part of the CNS. Be creative with this task, considering how you will demonstrate how signals are processed in the CNS.
4. Perform your role-play to one other group.

Peripheral Nervous System

The peripheral nervous system (PNS) is made up of nerves that extend from the central nervous system (CNS) to the rest of the body. It serves as a communication network connecting the brain and spinal cord to the organs, muscles, and skin. The PNS has two main parts: the cranial nerves, which come from the brain (to handle sensory, motor or mixed functions, primarily controlling head, neck and facial sensations, muscle movement and involuntary autonomic functions like digestion) and the spinal nerves, which come from the spinal cord (they facilitate voluntary movement, sensory perception like pain and touch as well as manage involuntary functions like heartbeat and sweat gland activity).

Functions of the Peripheral Nervous System

1. Carrying sensory information such as vision, smell, and hearing to the brain.
2. Controlling motor actions such as movements of the tongue, eyes, jaw, and lips.
3. Relaying information between the CNS and the body's organs and limbs.

Example: When you touch a hot object, the PNS quickly sends a message to the spinal cord and brain (CNS), which then sends a signal back through the PNS to move your hand away

Read the scenario below and try answering the questions that follow.

In a group of 3-5 members, discuss the question below and write down your answer in your notebook.

Emmanuel is a final-year student to give a speech at the national science fair. As he walks onto the stage, he starts to feel very nervous. His heart beats faster, his hands get sweaty, and he breathes more quickly. These changes happen automatically because his body is reacting to stress.

Once Emmanuel starts speaking and sees the audience smiling and clapping, he begins to feel more confident. His heart rate slows down, his breathing becomes normal, and he feels more relaxed. This happens because his body is calming down with the help of the nervous system, which controls how the body reacts in different situations.

After the speech, Emmanuel goes backstage. Someone gives him a hot drink in a cup. As he reaches for it, the cup slips a little in his hand. Without thinking, he quickly grabs it tighter and stops it from falling.

Emmanuel sits down and takes a sip of the warm drink. He feels proud of his speech and thankful for how his body helped him through it, from being nervous at first, to calming down and even reacting quickly to stop an accident.

a. Analyse the role of the autonomic nervous system in Emmanuel's physiological changes before, during, and after his speech.
b. Support your answer with specific references to both the sympathetic and parasympathetic nervous systems.

PERIPHERAL NERVOUS SYSTEM

Consider this: You step out onto the porch of your house, and suddenly your eyes widen; what? A snake! It is lying in the corner close to the wall. At the sight of it, a sudden chill runs through your body because you know snakes can be very dangerous. Instantly, without even thinking, you react in one of two ways. You either run away in fear or you gather courage and quickly look for a stick, stone, or anything you can use to kill the snake.

But here is the big question: What makes you choose whether to run (flight) or to fight?

Let us explore this together.

Note

- Autonomic Nervous System controls involuntary actions such as breathing and heartbeat and includes the sympathetic (triggers fight or flight by raising heart rate, blood pressure or dilating pupils) and parasympathetic (promotes rest and digest by lowering heart rate and stimulating digestion) systems. The sympathetic system mobilises energy for stress response, while the parasympathetic system conserves energy (resting state).
- Motor nerves carry instructions from the CNS to muscles and glands, enabling movement and response.
- Peripheral Nervous System (PNS) connects the central nervous system to the rest of the body and enables communication between the brain, spinal cord, and organs.
- Sensory nerves carry information to the CNS from sense organs like the skin, eyes, and ears.
- The Somatic Nervous System controls voluntary actions such as walking, writing, or picking up objects.

The Peripheral Nervous System (PNS)

The Peripheral Nervous System (PNS) includes all the nerves found outside the brain and spinal cord. It connects the central nervous system (CNS); which is the brain and spinal cord, to the rest of the body.

The PNS is made up of

1. Spinal nerves: They are arranged in 31 pairs and carry messages to and from the spinal cord.
2. Cranial nerves: They are arranged in 12 pairs and carry messages directly between the brain and different parts of the body, without going through the spinal cord.

Together, these nerves help the brain and spinal cord communicate with the body, allowing us to move, feel, and respond to the environment.

Spinal nerves emerge bilaterally from the spinal cord. These points of exit are the dorsal and ventral horns of the spinal cord. The ventral portion of a spinal nerve is responsible for transmitting information away from the CNS to effector organs like muscles and glands (that act in response to a nerve impulse or stimulus); this is known as efferent function.

Due to its role in controlling skeletal muscle movement, the ventral portion of the nerve is also commonly referred to as a "motor" nerve. On the other hand, the dorsal portion of the spinal nerve is afferent, meaning it carries sensory information towards the CNS. In summary, afferent axons provide sensory input to the CNS, while efferent axons enable the CNS to send motor commands to muscles, internal organs, and glands.

Types of the Peripheral Nervous System (PNS)

The peripheral nervous system (PNS) is organised into two main subdivisions: the somatic nervous system and the autonomic nervous system.

1. Somatic Nervous System (SNS)

The **somatic nervous system** is part of the peripheral nervous system that controls both sensing and movement. The sensory nerves in this system carry information from the skin (like pain and temperature) and from the muscles to the central nervous system (CNS).

This allows us to be aware of what is happening around us. The motor nerves carry instructions from the CNS to the skeletal muscles. This makes it possible for us to move our bodies voluntarily, such as walking, writing, or lifting objects. In short, the somatic nervous system helps us sense the environment and make voluntary movements in response.

2. Autonomic nervous system (ANS)

The autonomic nervous system (ANS) regulates the body's internal environment. It does this through a network of sensory and motor neurons that connect the central nervous system (especially the hypothalamus and medulla oblongata) to internal organs such as the heart, lungs, and both exocrine and endocrine glands. The autonomic nervous system (ANS) constantly monitors internal conditions and makes necessary changes to maintain homeostasis.

Motor neurons in the autonomic nervous system control the movement of smooth muscles (found in the walls of internal organs) and cardiac muscles (in the heart). Motor neurons in the autonomic nervous system control the movement of smooth muscles (found in the walls of internal organs) and cardiac muscles (in the heart).

In contrast to the somatic system, the actions of the autonomic nervous system are largely involuntary. Another important difference is that the autonomic nervous system (ANS) uses two neurons linked in a chain to send messages to organs, while the somatic system uses only one motor neuron.

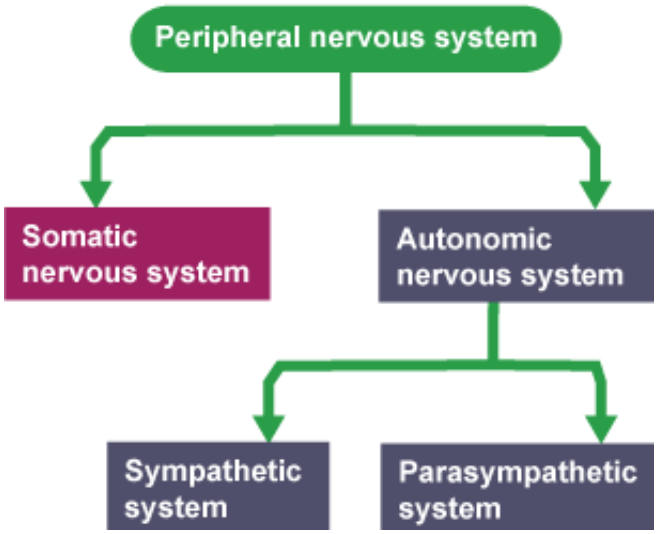


Figure 3.3: Peripheral nervous system

The autonomic nervous system (ANS) controls the body's internal environment without us thinking about it. It works through special sensory and motor nerves that connect the brain (especially the hypothalamus and medulla oblongata) to organs such as the heart, lungs, and glands.

The ANS is always checking the inside of the body and making changes to keep things balanced (homeostasis). It controls smooth muscles in the walls of internal organs and the cardiac muscle of the heart, helping to regulate functions like heartbeat, breathing, and gland activities.

Effector Tissues of ANS

These tissues are the targets of the ANS and are responsible for carrying out its functions. There are three types, which are

1. Smooth muscle: Found in the walls of blood vessels, the digestive tract, and other organs, smooth muscle contractions are controlled by the ANS.
2. Cardiac muscle: The heart muscle, responsible for pumping blood, is also regulated by the ANS.
3. Glandular tissues: The ANS controls the secretions of various glands, including salivary glands, sweat glands and digestive glands.

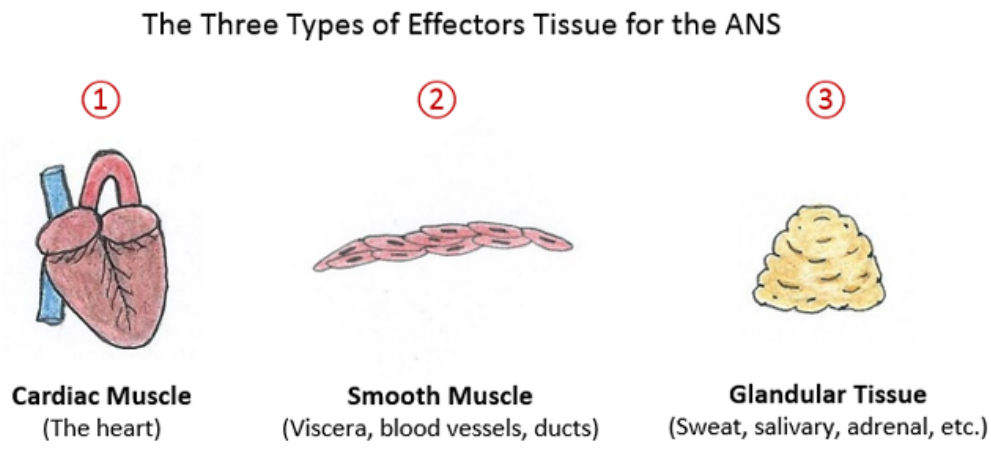


Figure 3.4: Types of effector tissues for ANS

Sympathetic and Parasympathetic Nervous Systems

The autonomic nervous system (ANS) has two main branches: the sympathetic and parasympathetic systems. The sympathetic and parasympathetic systems act on the same organs but in opposite ways. The sympathetic system prepares the body for "fight or flight," like when you are scared or in danger. It increases heart rate, breathing, and energy supply. On the other hand, the parasympathetic system helps the body rest, relax, and save energy.

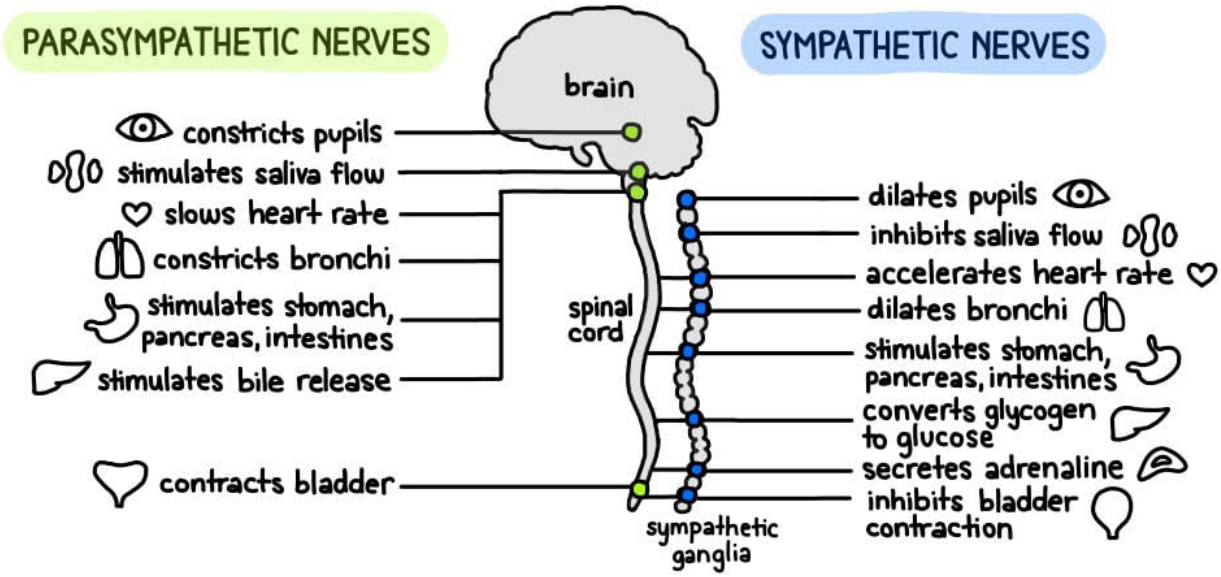


Figure 3.5: Sympathetic and parasympathetic nerves.

1. Sympathetic nervous system

In this system, there is a short nerve (called a preganglionic nerve) that comes from the brain or spinal cord and connects to a small group of nerve cells called a ganglion, which is located near the spinal cord.

At the ganglion, this first nerve releases a chemical called acetylcholine (ACh). This chemical passes the message to the next nerve (called the postganglionic nerve), which is usually long and thin.

The postganglionic nerve then carries the message all the way to a body part (like the heart). When it gets there, it releases another chemical (hormone) called norepinephrine (NE). This chemical attaches to special receptors on the body part (called alpha and beta receptors) to cause a specific response; like making the heartbeat faster.

The effects of norepinephrine release include

a. Stimulation of heartbeat, increasing heart rate.
b. Elevation of blood pressure.
c. Dilation of the pupils of the eyes.
d. Dilation of the trachea and bronchi, increasing airflow to the lungs.

e. Stimulation of glycogenolysis, the breakdown of liver glycogen into glucose, providing energy.
f. Shunting of blood away from the skin and viscera (internal organs) towards skeletal muscles, the brain, and the heart, prioritizing oxygen delivery to these critical areas.
g. Inhibition of peristalsis in the gastrointestinal (GI) tract, slowing down digestion.
h. Inhibition of contraction of the bladder and rectum, delaying elimination.

The sympathetic nervous system helps the body get ready to face or escape danger, a reaction often called "fight or flight." This wide response happens in two main ways. First, one preganglionic neuron can connect with many postganglionic neurons, spreading the signal to several organs at once. Second, the adrenal glands release adrenaline (epinephrine) into the blood, carrying the message to almost all cells in the body, even those not directly connected to sympathetic nerves.

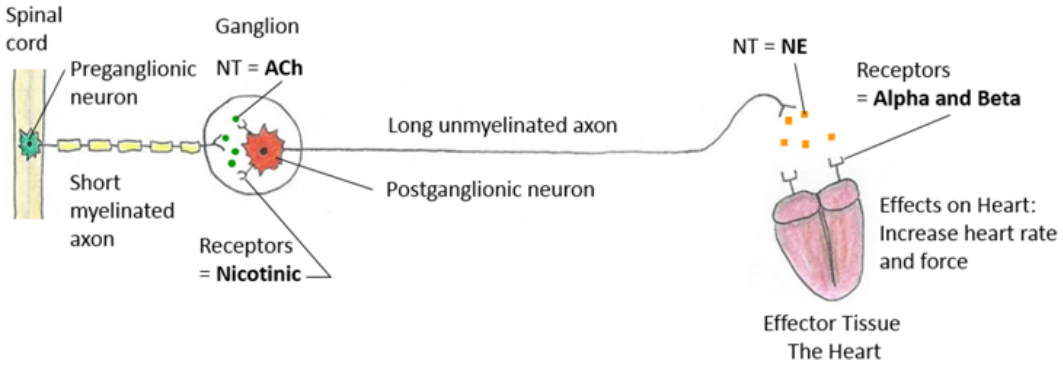


Figure 3.5: Sympathetic nervous system.

2. Parasympathetic nervous system

This part of the autonomic nervous system is called the parasympathetic system. It has long preganglionic nerves that come from the brain or spinal cord and travel to small groups of nerve cells (ganglia) that are very close to or inside the organ they control.

At the ganglia, the first nerve releases a chemical called acetylcholine (ACh), which passes the message to the postganglionic nerve. This second nerve is short and carries the message to the target organ (like the heart).

When the message reaches the organ, the second nerve releases ACh again, but this time it connects to muscarinic receptors on the organ. These receptors decide how the organ responds, such as slowing the heart rate or helping digestion.

Parasympathetic stimulation generally produces effects that are opposite to those of the sympathetic system, promoting a "rest-and-digest" state:

a. Slowing down of the heartbeat, decreasing heart rate.
b. Lowering of blood pressure.
c. Constriction of the pupils of the eyes.

d. Increased blood flow to the skin and viscera, supporting digestion and other restorative processes.

e. Stimulation of peristalsis in the gastrointestinal (GI) tract, promoting digestion.

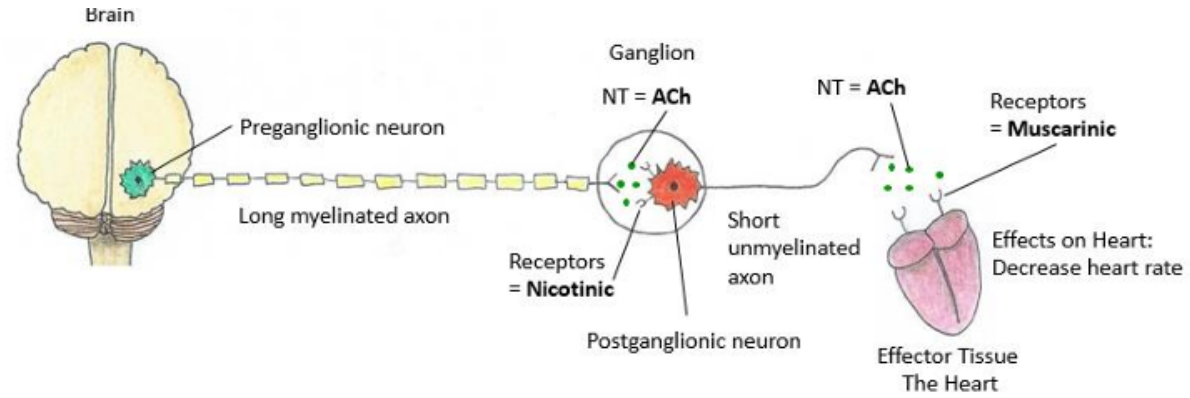


Figure 3.6: Parasympathetic nervous system

Balance between the sympathetic and parasympathetic nervous systems

1. The sympathetic and parasympathetic nervous systems work together to keep the body balanced and healthy (a state called homeostasis).
2. The sympathetic system helps the body get ready for action in stressful situations. It increases your heart rate, breathing, and blood pressure; this is called the "fight-or-flight" response.
3. The parasympathetic system helps the body calm down and recover after the stress. It slows the heart rate, lowers blood pressure, and helps with digestion; this is called the "rest-and-digest" response.
4. Both systems take turns depending on what your body needs at the moment, helping you stay safe, calm, and healthy.

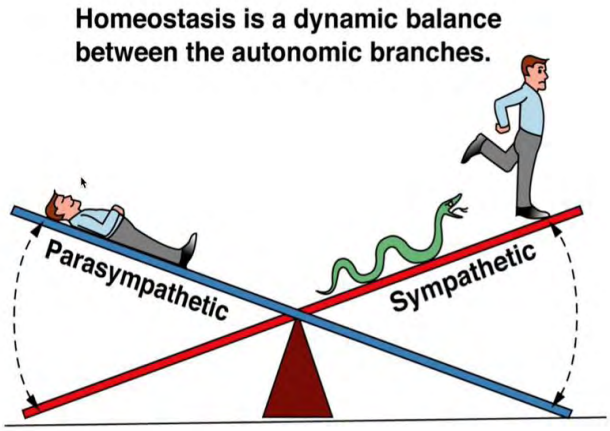


Figure 3.7: Balance between sympathetic and parasympathetic activity

Table 3.1: Difference between somatic and autonomic nervous systems

Somatic Nervous System	Autonomic Nervous System
Works voluntarily (under conscious control)	Works involuntarily (automatic, not under conscious control)
Controls skeletal muscles	Controls smooth muscles, heart muscles, and glands
Has only one motor neuron	Has two motor neurons (preganglionic and postganglionic)
Uses acetylcholine as the neurotransmitter	Uses acetylcholine or norepinephrine as the neurotransmitter
Always causes stimulation (excitatory)	Can either stimulate (excitatory) or slow down (inhibitory)
Controlled mainly by the cerebrum	Controlled mainly by the brain's centres (pons, hypothalamus, medulla)

Voluntary Action

Voluntary actions are activities that we can control. They can be started or stopped at any time by our choice. These actions are controlled by the brain (cerebrum).

Examples: walking, singing, eating, swimming, dancing, jumping, kicking a ball, and throwing a stone.

Involuntary Actions

Involuntary actions are activities that happen in the body without our control. They occur automatically, even if we do not notice them. Most are controlled by the spinal cord or brainstem, not the conscious brain.

Examples: heartbeat, breathing, blinking, dilation of pupils, salivation when smelling food, regulating body temperature, and dilation/constriction of blood vessels.

Table 3.2: Comparison of involuntary and voluntary actions

Involuntary Actions (Spinal Reflex)	Voluntary Actions
Controlled by the spinal cord, not under conscious control	Controlled by the forebrain, under conscious control
Impulse travels only in the spinal cord	Impulse travels from the brain down the spinal cord
A nerve impulse takes the shortest path	A nerve impulse takes a longer path
Response is immediate	Response can be delayed
Response can be in skeletal or internal involuntary muscles	The response is only in skeletal muscles

Perform this activity in a group of no more than 8 members.

Activity 3.4 Role-playing PNS

Aim: To understand how the Peripheral Nervous System (PNS) works

What you need

1. Labels or paper to show your role
2. A small object (like a ball or chalk) to represent a message

What to do

1. Form a group of 8 learners. Assign each person one of the following roles:
    a. Brain
    b. Spinal Cord
    c. Sensory Neuron 1
    d. Sensory Neuron 2
    e. Motor Neuron 1
    f. Motor Neuron 2
    g. Skin
    h. Muscle
2. Use your creativity to act out this situation: *"A person touches something hot."*
3. Act it out step-by-step
    a. The Skin feels the heat and passes the message (object) to Sensory Neuron 1.
    b. Sensory Neuron 1 passes it to Sensory Neuron 2.
    c. Sensory Neuron 2 sends it to the Spinal Cord.
    d. The Spinal Cord sends the message to the Brain.
    e. The Brain thinks and sends a command back to the Spinal Cord.
    f. The Spinal Cord sends it to Motor Neuron 1, then to Motor Neuron 2.
    g. Motor Neuron 2 gives it to the Muscle, which reacts by pretending to pull the hand away.
4. Each group member must say their role aloud when they pass the message (e.g., "I am the motor neuron. I send the command to the muscle!").
5. After the Role Play
    a. Draw a simple diagram in your books showing the path the message took.
    b. Write one sentence each to explain your role.

Activity 3.5 Study and recreate a diagram of the PNS

1. Ensure that you label your diagram in a detailed manner, including;
2. The key components, such as nerves, ganglia and sensory receptors
3. The functions of the somatic and the autonomic nervous systems
4. Examples of voluntary and involuntary actions
5. A comparison of the roles of the sympathetic and parasympathetic systems

Present your work to a few of your peers.

Activity 3.6 Nature walk

Go for a walk around your local area and allow yourself to notice all of the sensory experiences that you are getting. What can you smell, hear, feel, see, taste?

When you get back to the classroom, give an example of each of these senses being stimulated and explain how the PNS facilitates these experiences.

REFLEX ACTIONS

Let's build upon what we have already learnt about voluntary and involuntary actions. You might have, at some point, accidentally touched a hot cooking pot, heater or pressing iron; stepped on a sharp pin, iron nail or bone or had your knee touched suddenly. In each case, you reacted in a way that you did not initiate. What about the giggles that take you over as you are being tickled? All of these reactions of your body to the stimuli above do not come from the brain. Together, they are called reflex action.

Let us find out more about reflex action.

Notes

- **Reflex Action:** A reflex action is a fast, automatic, and involuntary response to a stimulus without conscious thought.
- **Functions of Reflexes**: Reflexes help protect the body from harm, allow quick reactions to danger, and maintain homeostasis.
- **Importance of Reflexes**: Reflexes are crucial for survival, support bodily functions like blinking and breathing, and reduce reaction time in emergencies.
- **Reflex Arc Structure**: A reflex arc is the pathway followed by nerve impulses during a reflex action, involving a receptor, sensory neuron, relay neuron, motor neuron, and effector.
- **Types of Neurons in Reflexes:** Reflex actions involve sensory neurons (carry impulses to the CNS), relay neurons (process the information), and motor neurons (carry impulses to muscles or glands).

Reflex action

A reflex action is a quick and automatic response to something that happens in or around the body. It does not involve thinking or decision-making.

The idea of reflexes was first explained by a scientist named Marshall Hall in the 1800s. He compared reflexes to how a ball bounces back when thrown against a wall; the body "reacts" quickly to a stimulus.

Reflex actions are natural and happen through the central nervous system (CNS) without involving the brain for conscious thought. For example, when you touch something hot, you quickly pull your hand away without thinking.

Examples of Reflex Actions

1. The pupil of the eye dilates or constricts when exposed to light of different intensities.
2. Sudden withdrawal of the hand or leg when pricked by a pin.
3. Coughing or sneezing caused by irritants in the nasal passage.
4. Knee-jerk reaction when the knee is tapped or stamped on.
5. Immediate withdrawal of the hand when it touches a sharp object.
6. Sudden blinking of the eyes when an insect comes very close.
7. Quick withdrawal of the hand from a hot object.
8. Watering (tearing) of the eyes when something falls into them.
9. The flow of breast milk when a baby sucks the mother's nipple.
10. Withdrawal of the leg when stepping on a sharp object.

A Reflex Arc

A reflex arc is the path that nerve impulses follow during a reflex. Some critical components which form the reflex arc are receptor organs, sensory neurons, nerve centres, associated neurons, motor neurons, and effector neurons. The stimuli are perceived by the receptor organs. Afferent neurons, also known as sensory neurons, transport stimuli from receptors to the spinal cord. The sensory neurons are found in the spinal cord's ganglion. The nerve centre, where synaptic connections are formed, is the spinal cord. Motor neurons are found in the ventral horn of the spinal cord. The glands and muscles that respond to stimuli are known as effector organs.

A simple reflex arc is summarised as follows

1. A receptor detects a stimulus (e.g., heat from a hot object).
2. A sensory neuron transmits the signal from the receptor to the central nervous system (spinal cord).
3. The sensory neuron connects with a motor neuron in the integration centre.
4. The motor neuron carries the signal from the integration centre to an effector.
5. The effector, which is either a muscle or gland that carries out the response (e.g., muscle contraction to move the hand away).

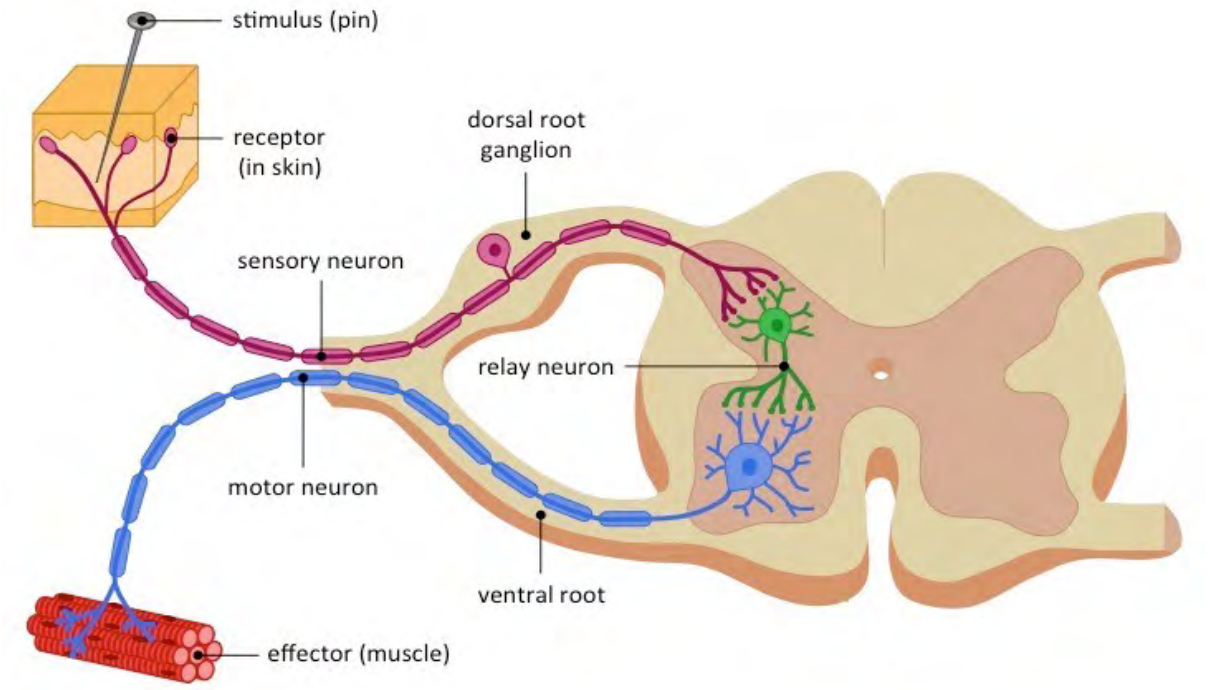


Figure 3.8: A reflex arc

Neurons and their Role in Reflexes

Most reflex arcs use only three neurons. Neurons are special nerve cells that are designed to carry electrical messages (impulses) from one part of the body to another. They are very important in reflex actions because they quickly link the sensory organs, spinal cord, muscles, and glands.

Neurons make up the main nervous tissue in animals (except simple ones like sponges and placozoa). Plants and fungi do not have nerve cells.

Each neuron has

a. **A cell body**: contains the nucleus and processes information.

b. **Dendrites**: branch-like parts that receive information and carry it to the cell body.

c. **Axon**: a long fibre that carries impulses away from the cell body to the axon terminals (end plates).

d. **Myelin sheath**: a fatty layer around the axon that insulates it and speeds up the message.

e. **Nodes of Ranvier**: small gaps in the myelin sheath that allow impulses to travel faster along the axon.

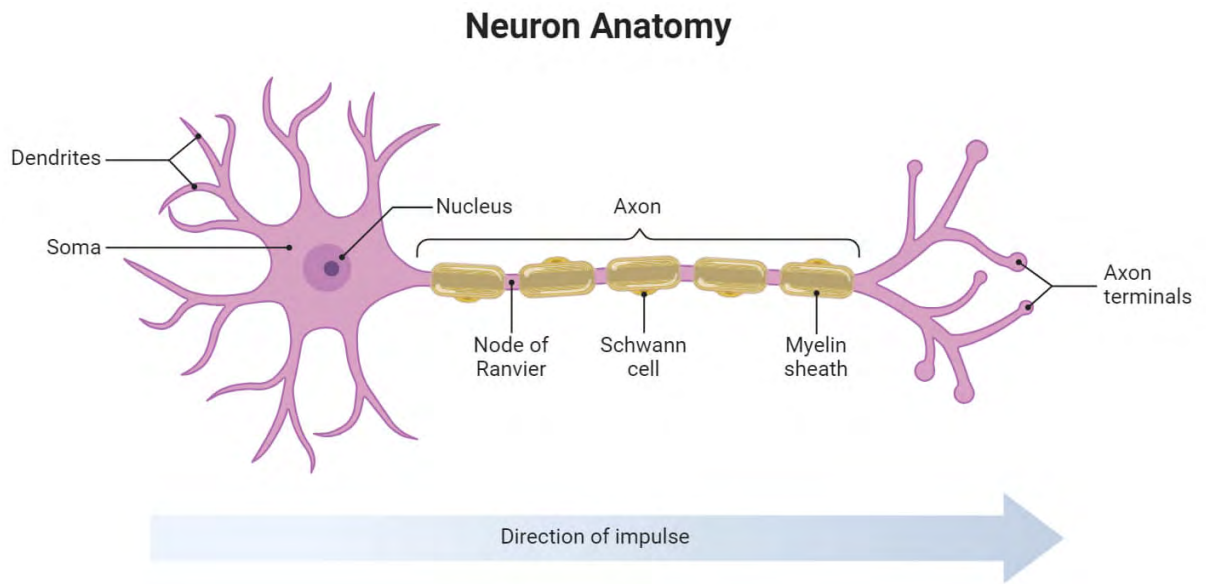


Figure 3.9: Structure of a neuron.

Classification of Neurons

Structurally, neurons can be put into the following classes based on the location of the cell body and the number of morphological processes emerging out of it:

a. **Unipolar neuron:** This is characterised by a single process extending from the cell body, which then splits into two branches, one acting as a dendrite and the other as an axon.

b. **Pseudo-unipolar neuron:** This is characterised by a single axon that splits into two branches shortly after emerging from the cell body.

c. **Bipolar neuron:** This is characterised by two processes, one axon and one dendrite extending from opposite sides of the cell body.

d. **Multipolar neuron:** This is characterised by one axon and multiple dendrites extending from the cell body.

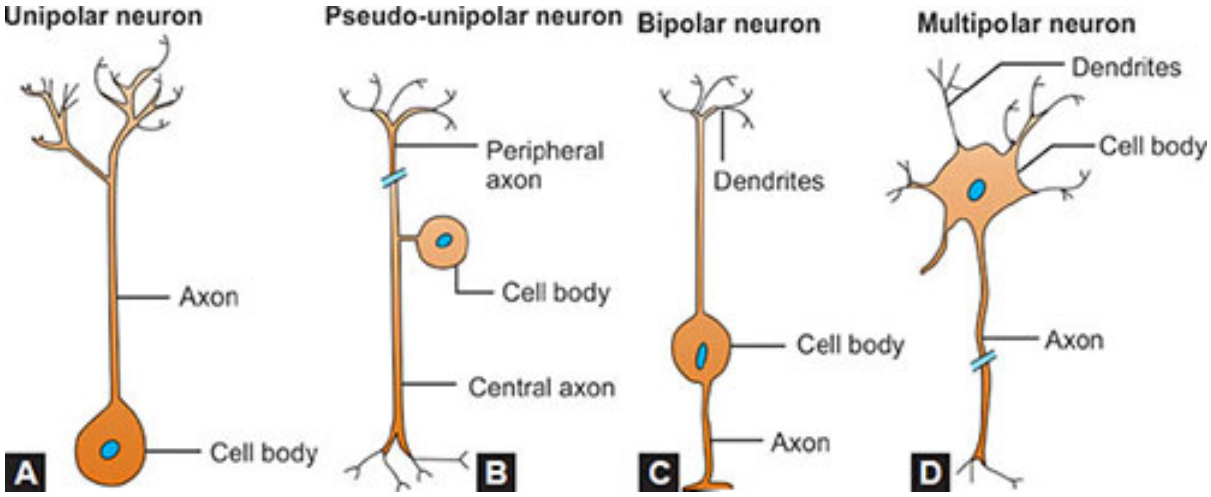


Figure 3.10: Classes of neurons.

Types of Neurons

Functionally, there are three types of neurons. These are

1. Sensory neuron
2. Relay neuron/Inter-neuron
3. Motor neuron

1. Sensory Neurons: They are also known as afferent neurons, and are nerve cells that convert stimuli from the environment (such as light, sound and pain) into electrical signals (action potentials) and transmit them to the central nervous system for processing.

They use a process called sensory transduction to convert stimuli detected through sensory receptors into action potentials

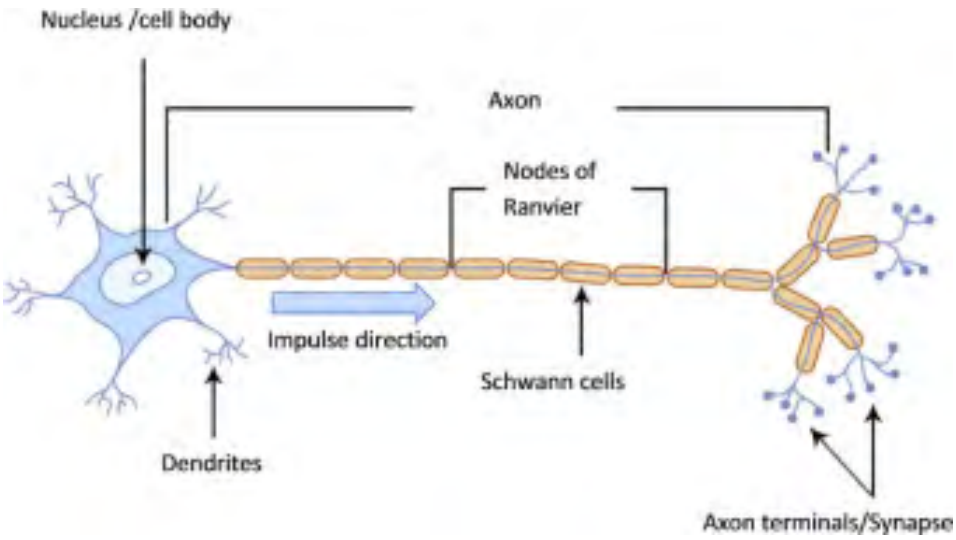


Figure 3.11: A sensory neuron

2. Relay Neuron/Inter-neuron: Relay neurons are only found in the central nervous system (the brain and spinal cord) and connect a sensory neuron to a motor neuron to facilitate reflex actions and complex processing. They are also referred to as associated neuron or intermediate neuron.

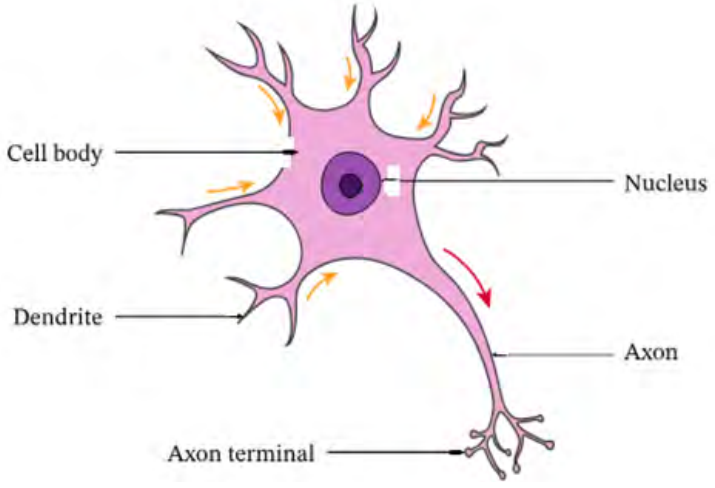


Figure 3.12: A relay/inter-neuron

3. **Motor neurons:** They are typically multipolar and their axon is often myelinated.

   They transmit signals from the central nervous system (brain and spinal cord) to muscles and glands, enabling movement and other bodily functions (voluntary and involuntary).

   It is also known as efferent neurons (since they carry impulses away from the central nervous system).

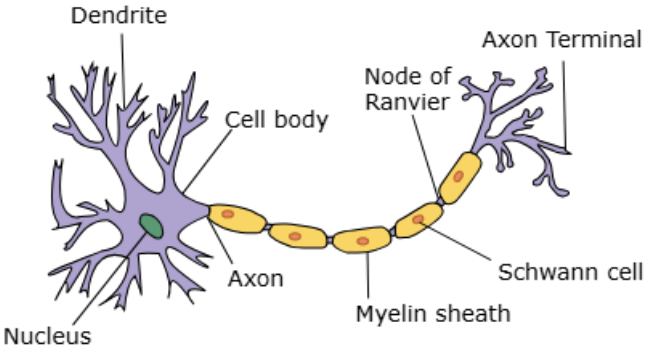


Figure 3.13: A motor neuron

Activity 3.7 Investigation Reflex Action

What you need

- Reflex hammer (or use your hand)
- Chair or bench
- Stopwatch (optional)
- Volunteer learner

What to do

1. Ask the volunteer to sit with their legs hanging freely.
2. Locate the patellar tendon below the kneecap.
3. Gently tap the tendon with the reflex hammer.
4. Observe the leg's automatic kick (knee-jerk reflex).
5. Repeat to compare reflex strength between both legs.

Discussion and analysis

1. Discuss with a few peers whether the body's response is voluntary or involuntary. Can the volunteer stop it from happening if they concentrate really hard?
2. Analyse/discuss the differences between voluntary and involuntary actions.
3. Create a concept map and/or an illustration to demonstrate the pathway of nerve impulses/reflex arcs.

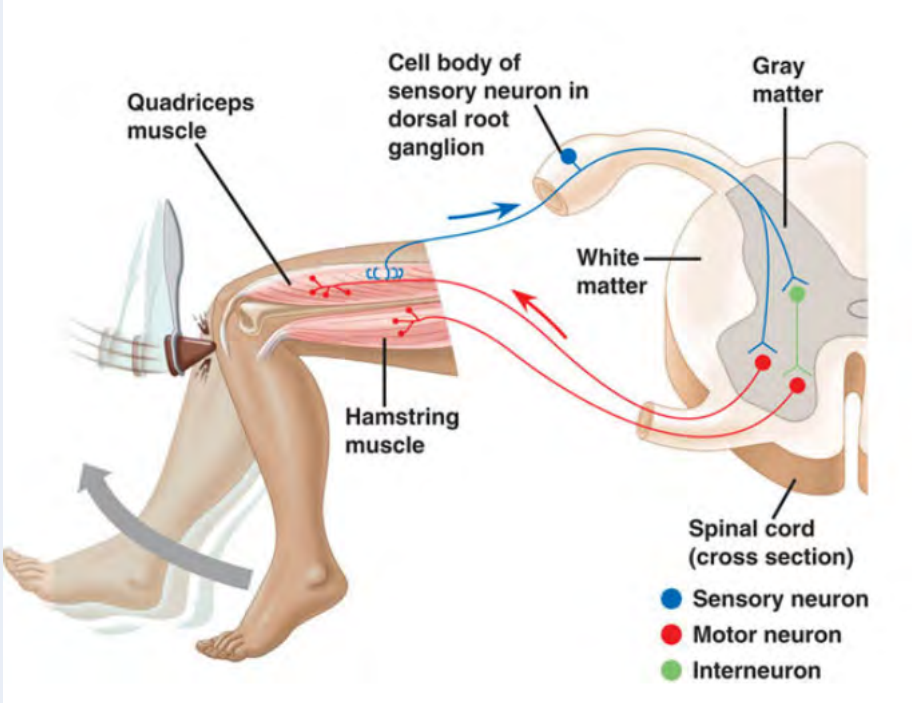


Figure 3.14: Reflex action

Activity 3.8 Research Neurological Disorders Affecting Neuron Function

Using the internet and any other resources available, investigate one neurological disorder or abnormality which affects neuron function. Create a short summary of the nature of abnormality and of the way in which it affects sufferers. Discuss treatments and management strategies.

Role Of Reflexes in Daily Life

Reflex actions are crucial for survival in the following ways:

1. **Protection**
   a. Avoiding Injury: Reflexes like withdrawing a hand from a hot or sharp object or blinking when something approaches the eye prevents potential injuries.
   b. Maintaining Balance: Reflexes help maintain posture and balance, such as automatically adjusting limb position when you trip or stumble.
2. **Movement and coordination**
   a. Basic Motor Skills: Reflexes, like the stepping reflex in infants, form the foundation for more complex movements like walking.
   b. Coordination: Reflexes help coordinate movements, allowing for smooth and efficient actions like catching a ball or avoiding obstacles.

3. **Homeostasis:** Reflexes contribute to maintaining a stable internal environment, such as shivering to generate heat when cold.
4. **Adaptation:** Reflexes allow the body to adapt to changing conditions, like adjusting pupil size in different light intensities.

GENERATION AND TRANSMISSION OF NERVE IMPULSES

In this section we will analyse the transmission of nerve impulses in further detail. The human body contains specialised cells called neurons, which are responsible for transmitting electrical signals; known as nerve impulses; throughout the body at high speeds.

These nerve impulses play a crucial role in enabling various functions, such as movement, sensation, memory, and perception. Whether it is feeling pain, enjoying the taste of food, or recalling important information, nerve impulses allow the brain to communicate effectively with different parts of the body in real time.

Note

- Neurotransmitters are chemical messengers that allow communication between neurons across synapses and can excite or inhibit the receiving neuron.
- Nerve impulses are electrical signals generated by changes in voltage across the neuron's membrane (action potentials) and travel along axons, especially fast in myelinated neurons.
- Synapses connect neurons through structures like axon terminals, synaptic clefts, and receptor sites, enabling one-way signal transmission.
- Synaptic transmission involves neurotransmitter release triggered by calcium ions, binding to receptors, and signal termination through reuptake or breakdown.
- Synapses perform vital functions such as integrating signals, directing signal flow, filtering weak stimuli, and supporting memory and behaviour.
- Neurons sum inputs through temporal and spatial summation, using excitatory (EPSP) and inhibitory (IPSP) signals, and can be modulated by chemicals that adjust their responsiveness.

Neurotransmitters

Neurotransmitters are special chemical messengers made by nerve cells (neurons) that enable neurons to communicate with each other, muscles or glands, controlling functions like movement, mood, sleep and heart rate. They are stored in small sacs called synaptic vesicles located at the end of a neuron (in the terminal buttons).

When a neuron is activated and sends an electrical signal (action potential), it causes these vesicles to release the neurotransmitters into a small gap between two neurons called the synaptic cleft.

The neurotransmitters then travel across this gap and attach to receptors on the surface of the next cell. This cell could be another neuron, or an effector cell, like a muscle or gland.

This process allows messages to pass from one cell to another, helping the body respond quickly and accurately to changes inside or outside the body (like muscle contraction or mood regulation). It is an essential part of how the nervous system works.

So far, scientists have discovered more than 100 different types of neurotransmitters. New ones are still being found as researchers learn more about how the brain and nervous system function.

Types of Neurotransmitters and Their Effects

Neurotransmitters affect how messages are passed between nerve cells. They can have two main effects on the next neuron (called the postsynaptic neuron)

1. Excitatory neurotransmitters

These increase the chance that the next neuron will send a signal (called an action potential), boosting activity in the brain.

Examples of excitatory neurotransmitters

a. Acetylcholine (ACh): Helps with muscle movement, learning, memory, and REM sleep.
b. Glutamate: The most common excitatory neurotransmitter in the brain. Important for learning and brain flexibility (also called neural plasticity).
c. Catecholamines: Dopamine and norepinephrine: Help with mood, alertness, focus, and body movement.
d. Serotonin: Affects mood, appetite, and sleep.
e. Histamine: Helps keep us awake and plays a role in immune system responses.

2. Inhibitory Neurotransmitters

These reduce the chance that the next neuron will send a signal. They help calm the brain and prevent overactivity.

Example: GABA (gamma-aminobutyric acid): The main inhibitory neurotransmitter in the brain. It relaxes the nervous system and prevents overstimulation.

3. Dual-Function Neurotransmitters

Some neurotransmitters can be either excitatory or inhibitory, depending on:

a. The type of receptor they attach to.
b. The situation in the body.

Example: Dopamine: It can excite or inhibit depending on the receptor type (like D1 vs. D2).

Table 3.3: Neurotransmitters and their functions

Neurotransmitters	Functions
Acetylcholine (ACh)	Affects movement, learning, memory, and REM sleep
Gama-Aminobutyric Acid (GABA)	Facilitates neural inhibition in the central nervous system (too much action potential), it is the brain's chill pill-it calms neurons, reducing activity and promoting relaxation, sleep, as well as lowering anxiety.
Endorphins	Provide relief from pain and promote feelings of pleasure and well-being. It acts like the body's natural painkillers
Dopamine (DA)	Controls voluntary movements of the body and affects movement, attention, learning, reinforcement, and pleasure. It acts like the brain's reward chemical
Norepinephrine (NE)	Affects eating, alertness, and wakefulness. It boosts energy and focus. Acts as the alert system
Epinephrine aka Adrenaline	Affects the metabolism of glucose, energy release during exercise and stress. Triggers the fight or flight response
Serotonin (5HT)	Affects mood, sleep, appetite, impulsivity, and aggression. It is like a mood stabiliser

Neurotransmitter Release

When a nerve signal (called an action potential) reaches the end of a neuron (the presynaptic terminal), it causes the membrane to change (depolarise). This opens calcium channels, and calcium ions (Ca^{2+}) enter the neuron. The calcium ions make small sacs called synaptic vesicles move and join with the cell membrane. These vesicles then release neurotransmitters into the gap between neurons (called the synaptic cleft); this process is called exocytosis. Once released, the neurotransmitters travel across the synaptic cleft and attach to special receptors on the next cell (the postsynaptic membrane). These receptors can be Ligand-gated ion channels (they open to let ions in or out). G protein-coupled receptors (they start slower, longer-lasting effects inside the cell).

Postsynaptic Effects

1. If the neurotransmitter opens channels that let positive ions in, the cell becomes more likely to fire (called depolarisation or EPSP).
2. If it opens channels for negative ions, the cell becomes less likely to fire (called hyperpolarisation or IPSP).
3. G protein-coupled receptors (cell surfaces that detect signals and activate internal responses) may affect the cell in other ways, such as changing enzyme activity or turning on/off genes.

How the Signal Stops (Neurotransmitter Inactivation)

Once the message is sent, the neurotransmitter must be removed so the cell can reset. This happens in three main ways:

a. **Reuptake:** The neurotransmitter is taken back into the original neuron or nearby support cells.
b. **Enzymatic Breakdown:** Special enzymes break down the neurotransmitter in the synaptic cleft.
c. **Diffusion:** The neurotransmitter simply moves away from the synapse into surrounding areas.

Neurotransmission

Neurotransmission is the fundamental process by which neurons communicate with each other and with effector cells (like muscle or gland cells) across synapses. It involves the generation and propagation of electrical signals within neurons and the conversion of these electrical signals into chemical signals that cross the synaptic gap.

Generation and Propagation of Nerve Impulses

A nerve impulse is an electrical signal that travels along a neuron (nerve cell). It allows the nervous system to send messages quickly between the brain, spinal cord, and other parts of the body.

1. **Resting Potential (Before the Impulse)**

   When a neuron is not sending a signal, it is said to be at resting potential. The inside of the neuron is negatively charged compared to the outside. This is because there are more sodium ions (Na^+) outside the cell and more potassium ions (K^+) and negatively charged proteins inside. The resting potential is about -70 millivolts (mV). It is like the ready state of the neuron, primed and waiting to trigger an action potential.

2. **Action Potential (Impulse Generation)**

   Nerve impulses, also known as **action potentials**, are quick electrical signals that travel along a nerve cell (neuron).

   a. **Depolarisation (Starting the Signal)**: When a stimulus (like a chemical message from another neuron) reaches a nerve cell, it causes the inside of the cell to become **less negative**. If this change reaches a certain level (called the **threshold**), special gates in the cell membrane open and let **sodium ions (Na^+)** rush into the cell. This makes the inside of the cell **more positive**, and more gates open in a **positive feedback loop**. The membrane potential can rise to about **+30 millivolts (mV)**. Depolarisation triggers the action potential (more like the spark that sparks the fire)
   b. **Repolarisation (Resetting the Signal):** Very soon after, the sodium gates **close**, and **potassium gates open**. **Potassium ions (K^+)** move out of the cell, making the inside **more negative again**. This step helps bring the nerve cell back toward its **resting state**.

c. **Hyperpolarisation (Brief Extra Reset)**: The potassium gates stay open a little too long, which makes the cell **even more negative** than usual. This is called **hyperpolarisation**. After this, the cell returns to its **normal resting potential**, ready to send another signal

3. **Transmission of the Impulse Along the Neuron**

   The action potential travels along the axon like a wave. As it moves, it opens ion channels in the next part of the axon, continuing the signal. This process is called propagation.

4. **Saltatory Conduction (Faster Transmission)**

   In myelinated neurons, the impulse jumps between gaps in the myelin sheath called Nodes of Ranvier. This makes the impulse travel much faster. This type of transmission is called saltatory conduction.

Regulation and Integration of Neural Signalling

Neurons receive input from multiple other neurons at synapses on their dendrites and cell bodies. These inputs can be excitatory (depolarizing) or inhibitory (hyperpolarising):

a. **Excitatory postsynaptic potentials (EPSPs):** Depolarisations that increase the likelihood of the postsynaptic neuron firing an action potential.

b. **Inhibitory postsynaptic potentials (IPSPs):** Hyperpolarisations that decrease the likelihood of the postsynaptic neuron firing.

Temporal and Spatial Summation

The postsynaptic neuron integrates these inputs through temporal summation (adding up EPSPs or IPSPs that occur close together in time) and spatial summation (adding up EPSPs or IPSPs that occur simultaneously at different locations on the neuron). If the combined effect of the inputs depolarizes the postsynaptic neuron to the threshold, an action potential is generated at the axon hillock and propagates along its axon.

Neuromodulator: In addition to fast synaptic transmission, neuromodulators can regulate neuronal activity. Neuromodulators are chemicals that don't directly excite or inhibit neurons but instead modify the strength of synaptic transmission or the excitability of neurons. They can act over longer distances and time scales than neurotransmitters.

Synapse

A synapse is the small gap between two nerve cells (neurons) where messages are passed from one neuron to the next.

Structure of a Synapse

1. **Presynaptic Neuron (Sender):** This is the neuron that sends the message.

   a. Axon terminal: The end of the neuron that connects to the next cell.

b. **Synaptic vesicles:** Tiny bubbles that carry neurotransmitters (the chemicals that carry the message).

c. **Calcium channels:** Let calcium in when a signal arrives. This helps release the message.

d. **Mitochondria:** Provide energy to the cell.

2. **Synaptic Cleft (The Gap):** A tiny space between the two neurons (about 20–40 nanometers wide). The message (neurotransmitters) jumps across this gap to reach the next neuron.
3. **Postsynaptic Neuron (Receiver):** This is the neuron that receives the message.

   Receptors: Special proteins that catch the neurotransmitters. When the receptors catch the chemical signal, a new electrical signal is made in the receiving neuron.

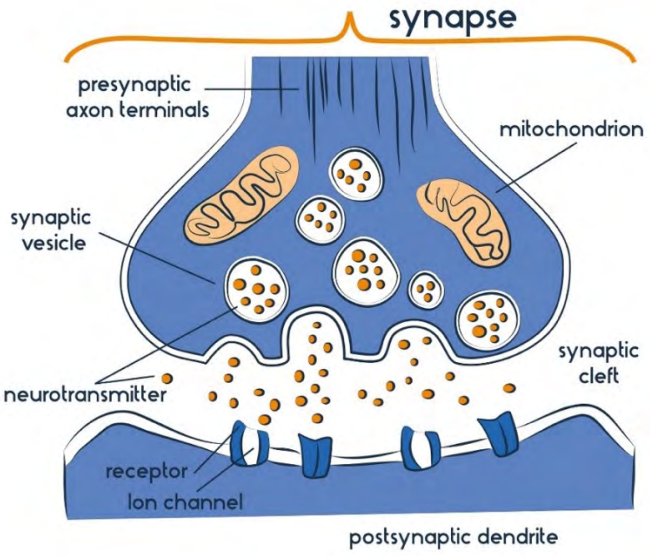


Figure 3.15: Synaptic transmission

Functions of synapse

1. Synapses in the CNS: In the central nervous system (CNS), synapses usually connect one neuron to another. These connections allow neurons in the brain and spinal cord to communicate, making learning, memory, and control of body functions possible.
2. Synapses in the PNS: In the peripheral nervous system (PNS), the postsynaptic cell can be another neuron or an effector cell like a muscle or gland. For example:

   a. At **neuromuscular junctions**, neurons connect to muscles, causing them to contract.

   b. At **neuroglandular junctions**, neurons connect to glands, leading to secretion of substances such as hormones.

3. One-way communication: Nerve impulses at synapses always travel in one direction; from the presynaptic neuron to the postsynaptic cell. This ensures that messages move in an organized way through the nervous system.

4. Filtering signals: Synapses can strengthen or weaken signals. Weak signals may be blocked so they do not activate the postsynaptic neuron, while strong signals that reach the threshold are passed on. This helps the brain focus on important information and ignore unimportant noise.
5. Role of neurotransmitters: Neurons communicate at synapses by releasing chemicals called neurotransmitters. These chemicals carry messages that control movement, feelings, perception, and thinking. If synapses do not work properly, it can lead to conditions such as depression, anxiety, epilepsy, or Alzheimer's disease.
6. Integration of signals: One neuron can receive signals from hundreds of others. Synapses help the neuron combine (integrate) these signals—some exciting, some stopping activity; and then decide whether to send a new signal. This process is important for decision-making in the brain.
7. Threshold for action: For a signal to cross a synapse, it must be strong enough to trigger an action potential (about +40 mV). If the signal is too weak, it will not pass on. This prevents the brain from being overloaded with weak or irrelevant information and allows attention to focus on important events like a loud noise or bright light.

Synaptic Transmission

Synaptic transmission is the process by which a signal is transmitted from one neuron to another or to an effector cell across a synapse. The CNS contains more than 100 billion neurons. The brain has 86 billion neurons. Some CNS neurons receive 20,000 synapses.

How Nerve Impulses Move Across a Synapse

When a nerve impulse (action potential) reaches the end of a neuron (called the terminal or axon terminal), it causes calcium (Ca^{2+}) channels in the membrane to open. As a result, calcium ions enter the neuron from outside.

This calcium triggers tiny sacs called vesicles (which contain neurotransmitters) to move toward the edge of the neuron. These vesicles fuse with the membrane and release neurotransmitters into the gap between two neurons. This gap is called the synaptic cleft.

The neurotransmitters then move across the synaptic cleft and attach to receptor sites on the next neuron (called the postsynaptic neuron). This triggers a response in the postsynaptic neuron:

a. If the neurotransmitter is excitatory (like glutamate), it causes sodium (Na^+) channels on the next neuron to open. Sodium flows in, causing the inside of the neuron to become more positive. If the signal is strong enough, it creates a new nerve impulse in the next neuron.
b. If the neurotransmitter is inhibitory (like GABA), it may open potassium (K^+) or chloride (Cl^-) channels. Potassium may flow out or chloride may flow in, making the inside of the neuron more negative, and making it harder for an impulse to start.

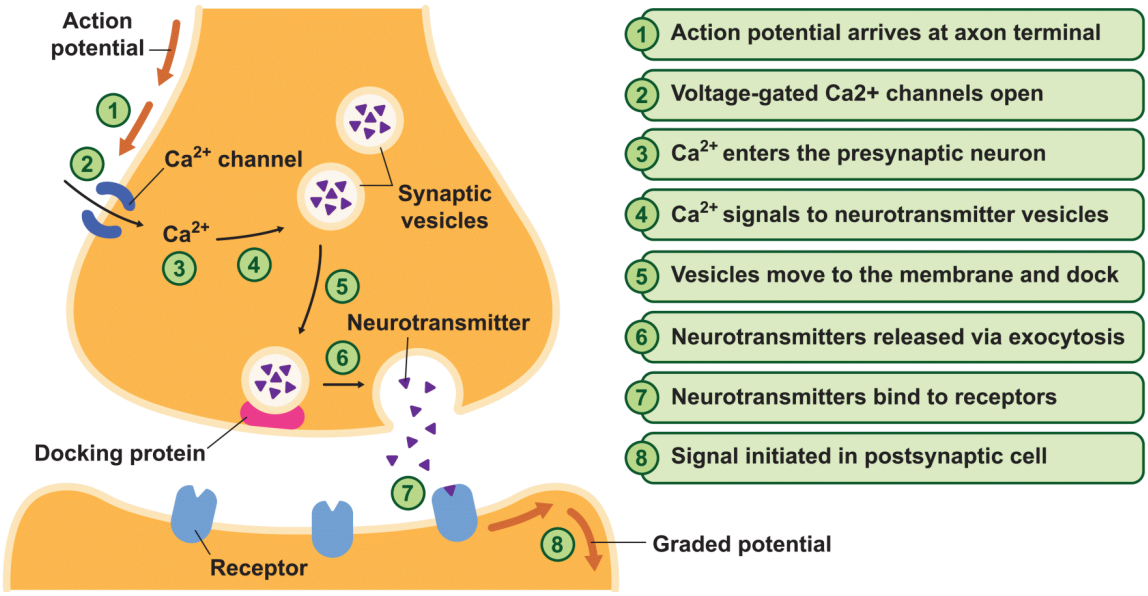


Figure 3.16: Synaptic Transmission

What Happens to Extra Neurotransmitters?

Not all neurotransmitters bind to receptors. The extras are removed in two ways:

1. **Reuptake**: The sending neuron takes them back for reuse.
2. **Enzymatic breakdown**: Special enzymes break them down. For example, acetylcholinesterase breaks down acetylcholine. These clean-up steps keep the synapse ready for the next signal.

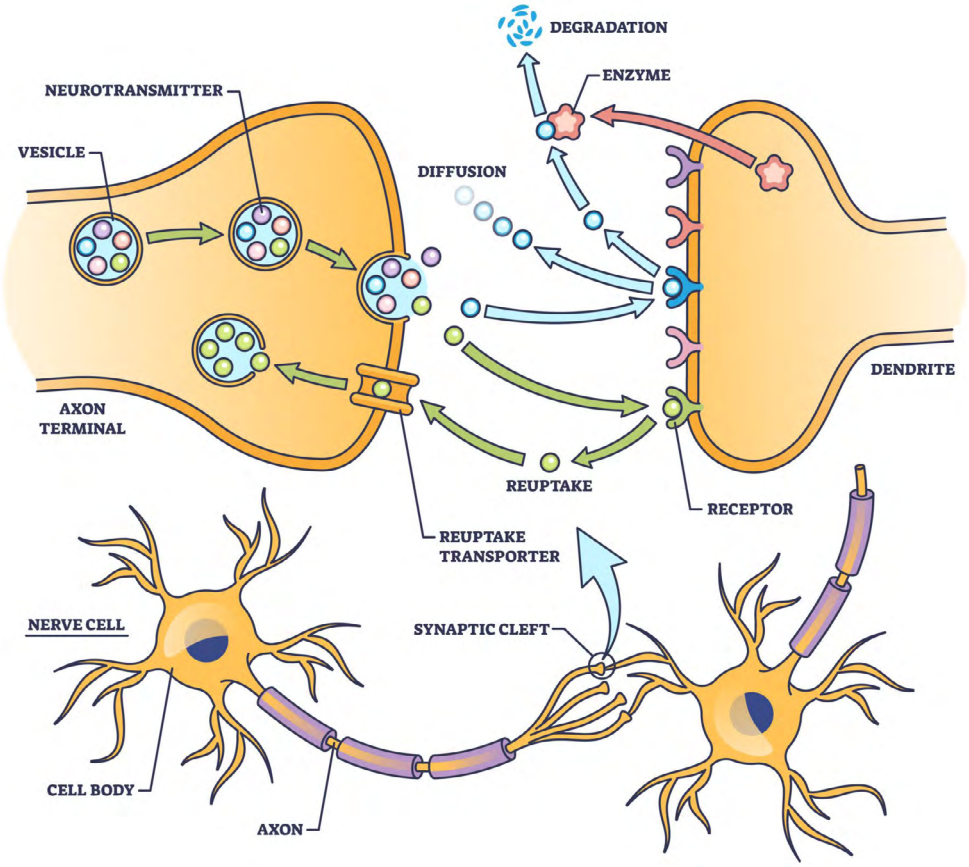


Figure 3.17: Reuptake of Neurotransmitters

Effect of Drugs Like Cocaine

Some drugs can interfere with this process. For example, cocaine blocks the reuptake of dopamine (a feel-good neurotransmitter). This causes dopamine to stay longer in the synapse and overstimulate the next neuron. That is why cocaine causes strong feelings of pleasure; but it also makes it highly addictive.

Activity 3.9 Modelling Nerve Impulse Generation

Aim: To understand generation and transmission of nerve impulses

What you need

- 10 dominoes or rectangular bars
- Ruler or meter stick
- Stopwatch
- Coloured tape (red, blue, green)
- Labels and markers
- Notebook for recording

What to do

Part A: Resting Potential Setup

Create Your Neuron Model

1. Arrange 10 dominoes in a straight line, spaced 2cm apart
2. *Label the setup*
   a. Red tape: Mark the first domino as "Stimulus point"
   b. Blue tape: Mark dominoes 2-9 as "Axon"
   c. Green tape: Mark the last domino as "Axon terminal"
3. *Record initial state*
   a. All dominoes standing represent Resting potential (-70mV)
   b. System is ready to receive stimulus

Understanding resting potential

a. Standing dominoes represent the neuron at rest
b. Negative charge inside the neuron (more K^+ inside, more Na^+ outside)
c. Stable state until stimulus arrives

Part B: Action Potential Generation (15 minutes)

Stimulus Application

a. Gently push the first domino (stimulus point)
b. Start the stopwatch as soon as you push

c. Observe the chain reaction as dominoes fall in sequence

d. Stop timing when the last domino falls

Record your observations

a. Time for complete transmission: _____ seconds

b. Speed of transmission: Distance ÷ Time = _____ cm/second

c. Pattern observed: Describe how the "impulse" travelled

Analyse the Process

Domino 1 (Stimulus point)

a. Depolarisation: Domino falls represent Na^+ channels open

b. Threshold reached: -55mV equivalent

Dominoes 2-9 (Axon)

a. Propagation: Each falling domino triggers the next

b. All-or-nothing: Each domino falls completely or not at all

c. Unidirectional: Signal travels in one direction only

Domino 10 (Axon terminal)

a. Signal arrives: Ready for synaptic transmission

b. Calcium channels open: Prepares for neurotransmitter release

Reset and Repeat

a. Stand all dominoes up represents repolarisation and return to resting potential

b. Repeat the experiment 3 times

c. Calculate average transmission time

Part C: Factors Affecting Transmission Speed

Experiment with variables

Test 1: Spacing Effect (Myelination)

a. Increase spacing to 4cm between dominoes

b. Time the transmission again

c. Compare speeds: Wider spacing results to faster transmission (like myelinated neurons)

Test 2: Obstacle Effect (Damage)

a. Place a small obstacle between dominoes 5 and 6

b. Observe what happens to signal transmission

c. Analyse: How does this relate to nerve damage?



Figure 3.18: Dominoes or rectangular bars

Activity 3.10 Research Task on an Aspect of Neurotransmission

Objective: Explore the fundamental processes of neurotransmission, focusing on how neurons communicate across synapses to transmit signals within the nervous system.

Choose One of the Following Focus Areas

a. Steps of neurotransmission: synthesis, storage, release, receptor binding, and termination.

b. Major neurotransmitters (e.g., glutamate, GABA, dopamine, serotonin, acetylcholine) and their roles.

c. The difference between excitatory and inhibitory signalling.

d. Mechanisms of synaptic plasticity and their importance in learning and memory.

e. How disruptions in neurotransmission contribute to neurological and psychiatric disorders.

What to do

Produce a brief summary of your chosen area, including labelled diagrams where appropriate.

Activity 3.11 Neuron Simulation

Click on the link below and spend some time becoming familiar with the PHeT simulation about neurons. Experient with changing variables and observing the effects.

Neuron 1.1.34

REVIEW QUESTIONS

1. Analyse what happens in your CNS when you ride a bicycle.
2. If someone had damage to their cerebellum, what difficulties would they experience?
3. A patient has a spinal cord injury that affects both somatic and autonomic functions

    a. Differentiate between the somatic and autonomic symptoms that might occur.
    b. Explain why some reflexes might still work below the injury level.
    c. Analyse the challenges this creates for homeostasis.
    d. Discuss how the body might compensate for lost autonomic control.

Scenario

On her way home from school, Fatima suddenly heard the screeching of tyres. In an instant, she jumped back onto the sidewalk, narrowly avoiding a speeding motorcycle. She later noticed her heart racing, her hands trembling, and her breathing becoming faster. Fatima realised she had not made a conscious choice to move; her body had reacted automatically. Her biology teacher used this incident as a case study and challenged the class to investigate what had happened inside Fatima's body. Learners were asked to examine her response as a reflex action, compare it with voluntary movement, and explain why reflexes are essential for survival.

4. Analyse the sequence of events in Fatima's response and identify the following.

    a. The stimulus
    b. The sensory neuron
    c. The interneuron (relay neuron)
    d. The motor neuron
    e. The effector (muscle or gland)

5. A postsynaptic neuron receives the following inputs simultaneously:

3 excitatory inputs (each +2 mV)

2 inhibitory inputs (each -3 mV)

Threshold = +3 mV

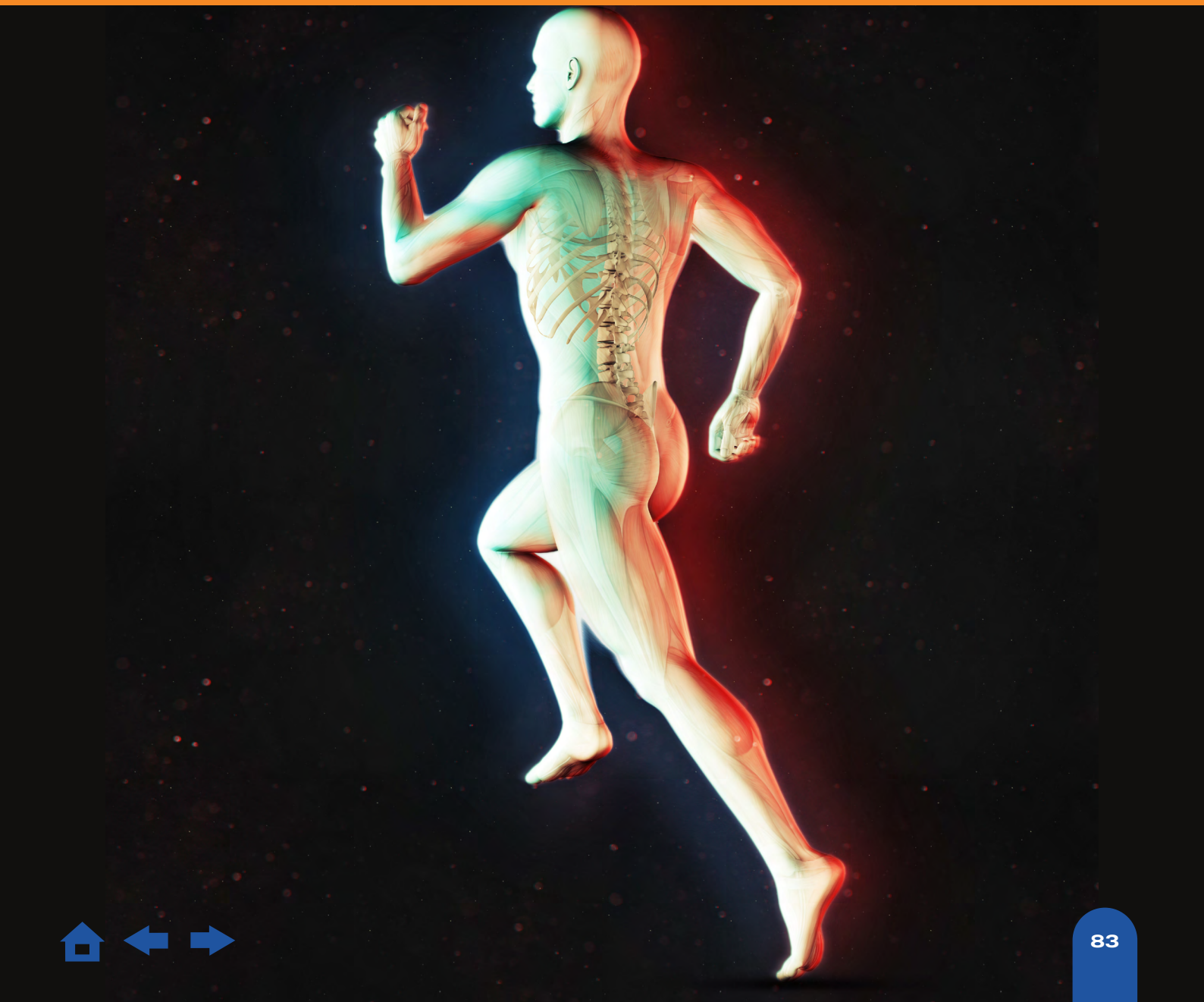
Analyse the information given and do the following.

    a. Calculate the net effect on the postsynaptic neuron
    b. Determine if an action potential will be generated
    c. Explain how this demonstrates synaptic integration
    d. Predict what would happen if one more inhibitory input were added

SECTION

4

MOVEMENT OF VARIOUS PARTS OF THE HUMAN BODY



PROCESSES FOR LIVING

INTRODUCTION

The human body relies on the skeleton and muscles to give it shape, protect vital organs, and make movement possible. In this lesson, we will study the musculoskeletal system, which includes the bones, muscles, joints, and connective tissues that work together to support the body. The lesson will examine how the human skeleton is structured and how it works with muscles to produce movement. You will also learn about the three main types of muscle tissues found in the human body. Skeletal muscles are attached to bones and help us make voluntary movements such as walking or writing. Smooth muscles are located in the walls of internal organs like the stomach and intestines; they control involuntary actions such as digestion. The third type, cardiac muscle, is found only in the heart and helps to pump blood throughout the body continuously. Through observation, modelling, and classroom discussions, you will gain a deeper understanding of how the bones and muscles depend on each other. You will explore how they work together to produce movement, maintain body posture, and protect delicate organs such as the brain, heart, and lungs. By the end of this lesson, you should be able to explain how the musculoskeletal system supports life and activity in the human body.

KEY IDEAS

- The axial and appendicular skeletons form the two main divisions of the human skeleton.
- The skeletal system is made up of bones, joints, and connective tissues such as cartilage and ligaments.
- The human skeleton performs several important functions, including support, movement, protection of internal organs, and production of blood cells.
- The main parts of the human skeleton include the skull, vertebral column, rib cage, and limbs.
- There are different types of skeletal systems found in living organisms, such as exoskeletons, endoskeletons, and hydrostatic skeletons.

SKELETAL SYSTEM

Hello, learners. Have you ever come across the bone remains of a dead animal? Have you wondered what those bones were doing in the body of the animal and the parallels between that and our own bodies? This week, we are embarking on a trip into the human body to study its bony framework known as the skeletal system.

Skeletal material

The skeletons of animals are made of three types of materials. These are:

1. Chitin: It is the major component of the skeleton of arthropods. It is a tough, light and flexible material. Chitin is made of carbohydrate (cellulose) and strengthened by deposits of hardened proteins and minerals. Organisms whose skeleton is made of chitin include crustaceans (crabs, lobsters, shrimp) and arachnids (spiders, scorpions)
2. Cartilage: Cartilage is made of living cells (called chondroblasts), carbohydrates and protein fibres. It is a tough and flexible tissue that has great tensile strength. It acts as a shock absorber and protects bones from rubbing against each other during movement. The skeleton and entire system of sharks, rays, skates and foetuses are made of cartilage: In humans, cartilage occurs in the ear, nose, discs between the vertebrae of the vertebral column, trachea, bronchi, epiglottis and the Eustachian tube. Cartilage does not have its own blood supply vessels but depends on the oxygen and nutrients that diffuse across nearby tissues.

   There are three types of cartilage. These are hyaline cartilage, fibro-cartilage and elastic cartilage.
3. Bone: Bones are hard, living connective tissue that provide structural support, protect organs, facilitate movement and store minerals like calcium. It is composed of compact and spongy tissue and contains specialised cells (osteoblasts, osteocytes, and osteoclasts) that constantly build, maintain, and reshape the tissue through a process called bone remodelling.

Activity 4.1 Identifying cartilage

Aim: To identify cartilage through touch.

What to do

1. Individually, feel your ears by probing them gently with your hands.
2. Repeat by doing the same to your nose.
3. Touch other body parts such as lips, cheeks, neck and arms. Can you find any other areas which feel similar to the ears and nose, and are therefore made of cartilage?
4. Record your observations and findings.

Discussion

1. Discuss your observations and findings in small groups of four and share ideas with other groups.
2. List all structures in the human body made of cartilage for a class discussion.

Types of skeletons

The main types of skeletons in animals are Endoskeleton, Exoskeleton and Hydrostatic Skeleton.

1. Endoskeleton

This is an internal structure which mainly provides support in all vertebrates. It is primarily composed of bones and cartilage. Bones are living, dynamic tissues that constantly build, maintain, and reshape themselves. This process is called bone remodelling. Bones are generally hard and strong. This hardness and strength come mainly from the presence of calcium salts, which are mineral substances, in them. The presence of calcium compounds in bones makes them rigid and capable of supporting body weight. Where two bones meet in the body (such as in the hip, knee, or elbow joint), their contacting surfaces are covered with a pad of cartilage (also known as gristle).

The function of this cartilage pad is to

1. Reduce friction between bones during movement.
2. Act as a shock absorber to prevent damage from impact.

Examples of vertebrates with endoskeletons include the following listed below.

1. Mammals such as cows, rats, humans, rabbits and bats.
2. Reptiles such as snakes, lizards and crocodiles.
3. Bony fish such as tilapia.
4. Birds.

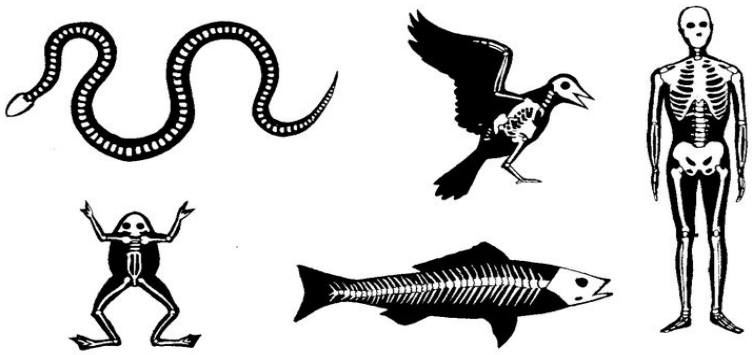


Figure 4.1: Some vertebrates with an endoskeleton.

2. Exoskeleton

This is a hard, external covering mainly composed of chitin. It protects and supports the bodies of some invertebrates, particularly arthropods. It is made of a tough, flexible polysaccharide that resembles cellulose. Animals with this type of skeleton undergo periodic moulting or shedding of their exoskeleton in a process called ecdysis in order to grow. This happens because exoskeletons are rigid and non-expandable, which, if not shed, will not allow growth of the animal to take place.

Examples of animals that have exoskeletons include spiders, crabs, lobsters, millipedes, centipedes, houseflies, cockroaches, butterflies, and beetles.

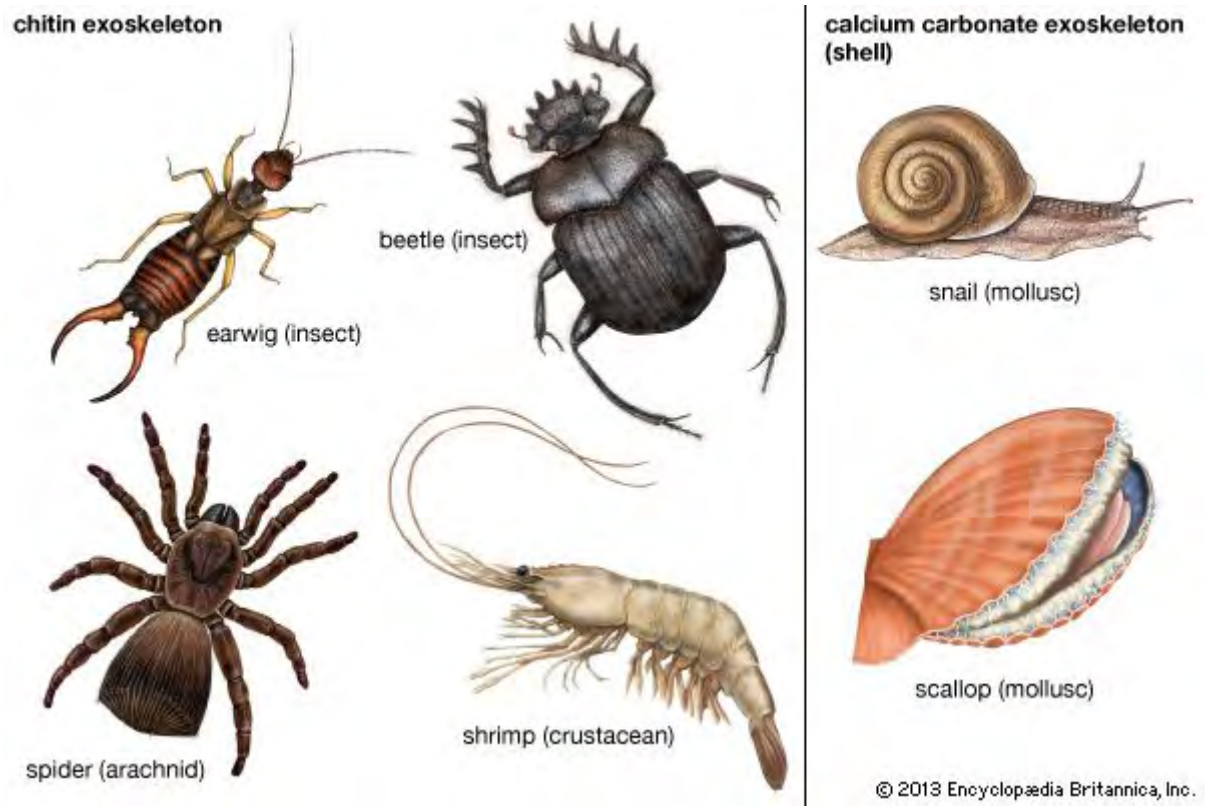


Figure 4.2: Some invertebrates with exoskeleton.

3. Hydrostatic skeleton

This type of skeleton is found in soft-bodied invertebrates. Such animals rely on the pressure of internal fluid to maintain shape and enable movement. The skeleton consists of a fluid-filled cavity surrounded by muscles. When muscles contract around the cavity, the incompressible fluid inside the cavity provides rigidity and support, allowing the animal to move or maintain its form. Examples of animals with hydrostatic skeletons include earthworms, maggots, jellyfish, and sea anemone.

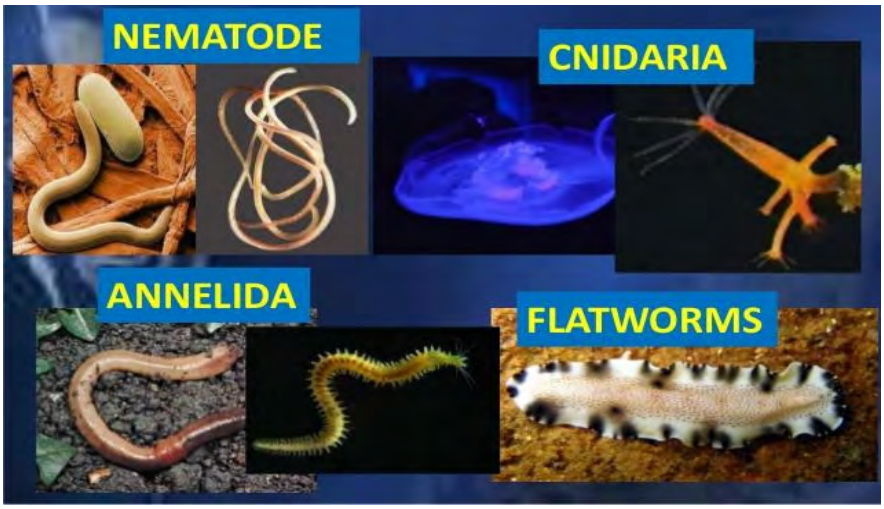


Figure 4.3: Some soft invertebrates with a hydrostatic skeleton.

Let us do the following activity to find out how the different kinds of skeletons help living organisms. Do this in a group of four members.

Activity 4.2 Investigating Skeletons

Aim: To explain how different skeletons support movement, protect, and ensure survival across different species and environments.

What to do: In a group of 6 learners, split into pairs and research the functions of different types of skeletons (endoskeleton, exoskeleton and hydrostatic skeleton).

Consider the following questions.

1. How does this kind of skeleton support movement?
2. How does it protect the animal?
3. How does it ensure survival?

Discussion: Write down your findings and discuss them among yourselves and with the other pairs in your group. Use your findings to prepare a chart of the three types of skeletons. Present your chart for class discussion and critique and arrange them for a gallery walk.

Functions of the mammalian skeleton

1. **Structural framework:** It gives the body its basic shape and structure.
2. **Body shape:** It helps to define the physical form and posture**.**
3. **Support:** It holds up the body and keeps it upright.
4. **Protection:** The skull protects the brain, the ribcage shields the heart and lungs, and the vertebrae protect the spinal cord.
5. **Surfaces for muscle attachment:** Bones have projections and ridges (called facets) where muscles attach to facilitate movement.
6. **Movement:** Bones, in combination with muscles and joints, allow for complex movement.
7. **Blood cell formation:** The bone marrow, found in the central cavities of certain bones, produces red blood cells, white blood cells, and platelets in a process called haematopoiesis.
8. **Stores minerals:** Bones serve as reservoirs for important minerals, particularly calcium and phosphorus, which can be released into the bloodstream when needed.

Key question: Consider a human body without a bony skeleton. How do you think such a body could function?

Structure and Composition of Bone

Bone is a **living connective tissue** made up of both **organic and inorganic components**, giving it a unique combination of **strength, rigidity, and lightness**.

It consists of;

1. **Living bone cells** known as **osteocytes**.
2. **Protein fibres** primarily **collagen**, which provide flexibility and tensile strength.
3. **Mineral salts**, mainly **calcium phosphate** and **calcium carbonate**, which provide hardness and rigidity.

Approximately **two-thirds** of the bone mass is made up of **inorganic mineral salts** (non-living), while **one-third** consists of **organic materials** (living cells and protein fibres). Unlike cartilage, **bone has its own blood supply**, which allows for active nourishment, growth, and repair. This vascularisation (the physiological process of developing new blood vessels to deliver oxygen and nutrients) makes bone a dynamic tissue that can remodel and heal when damaged

Ossification (Bone formation)

The process of **ossification** refers to the **development of bone tissue** and the **deposition of minerals**, such as **calcium phosphate** and **calcium carbonate,** into a tissue matrix, replacing cartilage or fibrous tissue to form hardened bone. Ossification occurs during **foetal development**, **growth in children and adolescents, fracture healing,** and throughout life as part of **bone remodelling.**

There are two types of ossification

1. **Intramembranous ossification:** Where bone develops directly from mesenchymal (embryonic connective) tissue, e.g., in flat bones of the skull.
2. **Endochondral ossification:** Where bone forms by replacing cartilage (e.g., in long bones like the femur).

Structure of a Long Bone

A long bone, such as the femur (the longest and strongest bone in the body that connects the hip to knee) or humerus a long bone in the upper arm connecting the shoulder to elbow), in humans has two distinct regions. These are:

1. **Compact bone:** This makes up the hard outer shaft (diaphysis). It is dense and strong and contains Haversian systems (osteons). These are structural units made of concentric rings of bone matrix (lamellae). The lamellae are arranged around Haversian canals. Osteocytes (bone cells) are located in small spaces called lacunae. Tiny channels, called canaliculi, connect lacunae, allowing nutrients and waste to pass between osteocytes and nearby capillaries.
2. **Spongy/cancellous bone:** This makes the expanded ends of the bone (epiphyses). It has a honeycomb-like structure with numerous bony struts called trabeculae. It contains red bone marrow within its spaces, which produces blood cells. Despite its porous appearance, it is well-adapted to withstand compressive forces.

   Bone marrow: This is a soft spongy tissue found inside larger bones. There are two types, namely, red bone marrow and yellow bone marrow. Red bone marrow, also known as myeloid tissue, is found in the spongy bone of the epiphyses. It contains haematopoietic (blood-forming) stem cells that constantly produce new red blood cells, white blood cells, and platelets. Yellow bone marrow, which is composed mostly

of fat, is contained in the medullary cavity of the shaft. It contains mesenchymal stem cells that can develop into cartilage, fat, or bone cells.

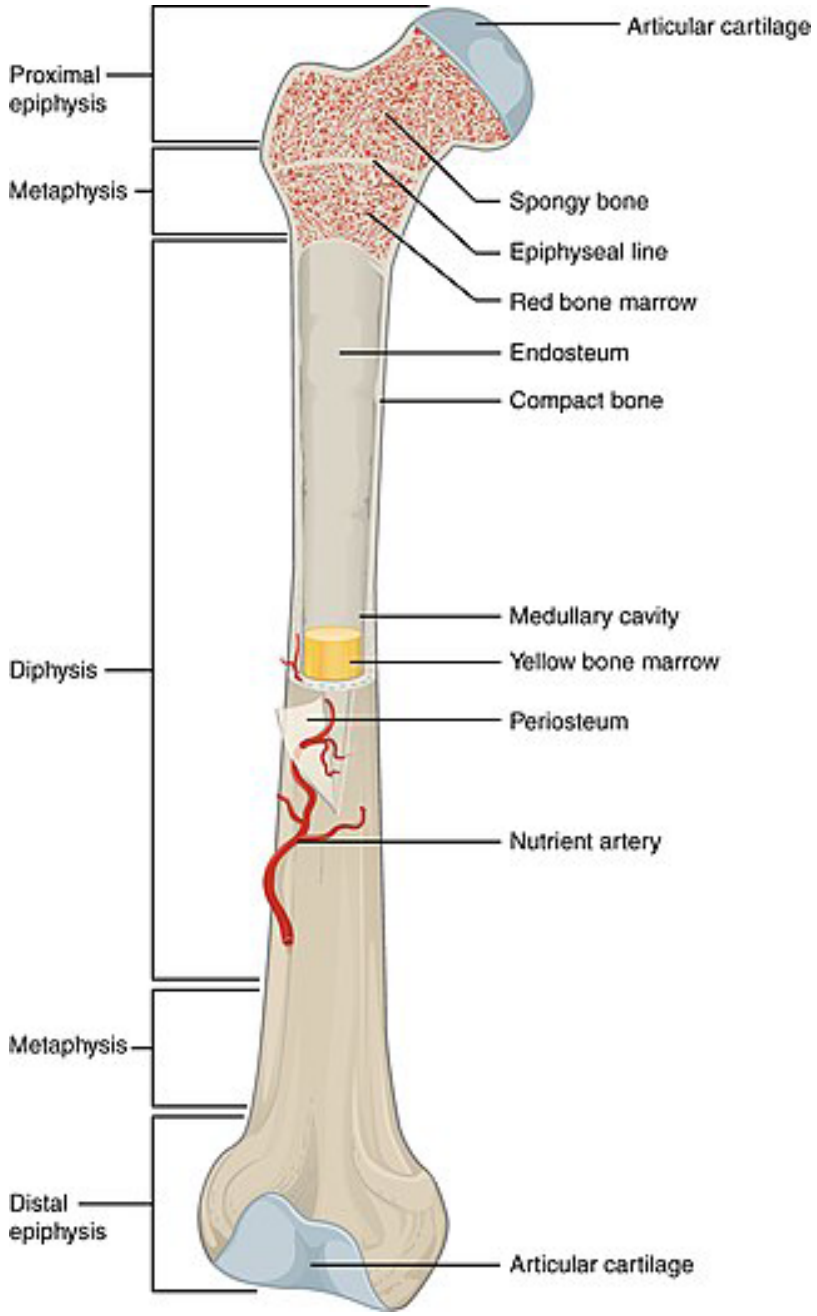


Figure 4.4: Structure of a long bone

Adaptation of bone structure

Structurally, a bone is designed to possess the following adaptations

1. Light but strong: Ideal for mobility and support.
2. Ability to withstand stress and pressure: Achieved through the strategic arrangement of trabeculae in spongy bone to resist compression forces.
3. Ability to exchange nutrients and waste: Takes place via vascular and neural access through bone canals and pores.

Parts Of the Mammalian Skeleton

The mammalian skeleton consists of the following major parts;

a. Skull
b. Vertebral column.
c. Limbs and limb girdles.

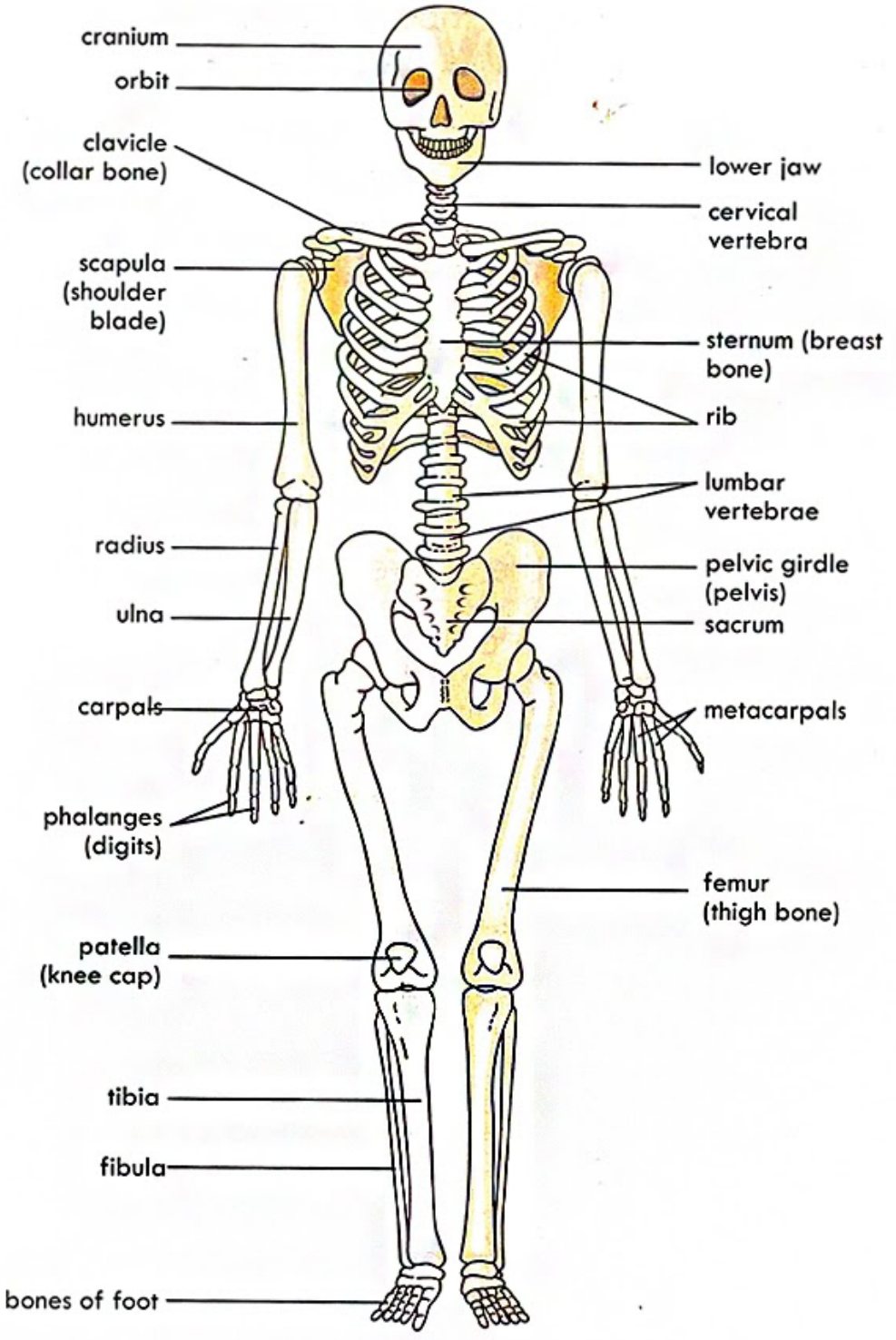


Figure 4.5: The human skeleton

Activity 4.3 Cutting and building a human skeleton model

Aim: Identify various parts of the human skeleton.

What you need: Pictures of the human skeleton printed on manila cards.

page1.pdf



a. Cutters such as knives and pairs of scissors.

b. Needle and thread to sew cut parts together.

What to do

1. In a group of five, cut out the skeleton on the card.
2. Using the needle and thread, each member sews together the cut pieces.
3. Each member would be expected to mount their model for the identification of the various parts.
4. Label your skeleton with the names of the major bones, joints and the locations of any known muscles.

Precaution: Care must be taken in perforating the card with the needle in order not to dismember the cut parts.

TYPES OF THE MAMMALIAN SKELETON

There are two main divisions. These are axial and appendicular skeletons.

Axial Skeleton

The axial skeleton forms the central axis of the body and consists of the following parts

a. Skull
b. Vertebral column (Backbone or spine)
c. Ribs and sternum (Breastbone)

This is the body's main frame

Skull: The skull is a bony structure composed of several separate bones formed by intramembranous ossification. It protects the brain and houses vital senses – eyes, ears, nose and mouth. The bones can be divided into those of the cranium and those of the face.

The cranial bones are flattened and thick and are fused by immovable joints called sutures. Key among the facial bones are the upper jawbone (maxilla) and lower jawbone (mandible). In humans, the maxilla is movable and is used for biting and chewing food.

The cranium (braincase) protects the brain, while facial bones provide cavities (orbits) to house and protect the eyes and structures that protect the ears and nose.

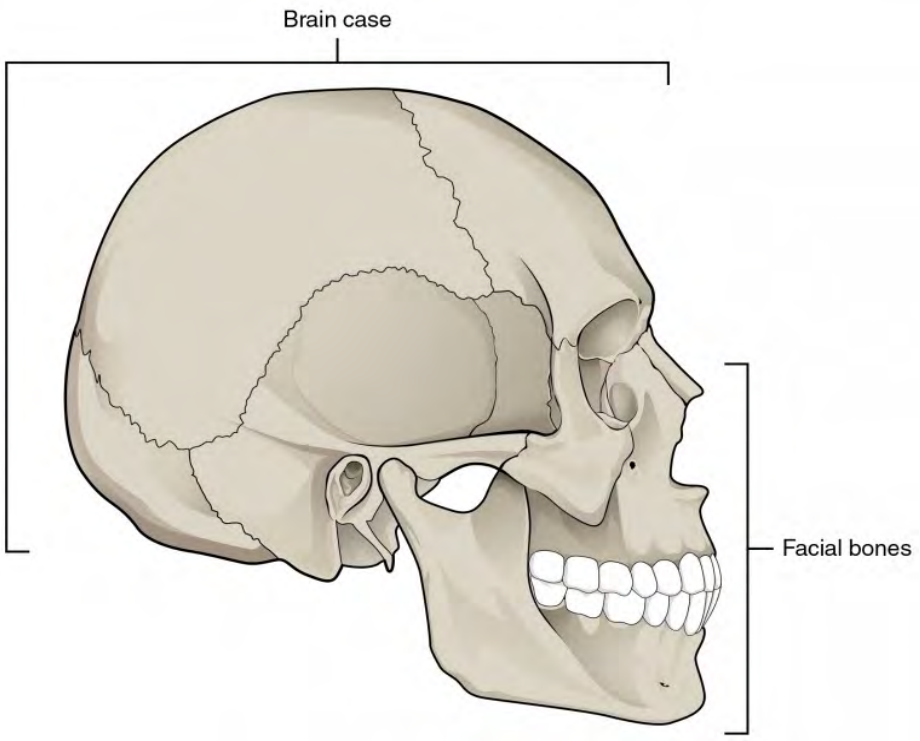


Figure 4.6: Human braincase and facial bones

Vertebral Column (Backbone or Spine): This runs along the dorsal (back) side of vertebrates. In humans, it starts from the base of the skull and ends at the pelvis (sacrum). In mammals with a tail, it ends in caudal vertebrae, which extend to form the tail.

The vertebral column is composed of individual bones called vertebrae. These are joined end to end to form a flexible, protective tube which houses the spinal cord. Between each pair of vertebrae are intervertebral discs made of cartilage and fibrous tissue. These act as shock absorbers and allow flexibility and movement.

The vertebral column provides support for the body during various kinds of movement, attachment for muscles, and protection for the spinal cord.

There are five main groups of vertebrae in humans and most mammals. These are shown in **Table 4.1** below.

Table 4.1: Groups of vertebrae in humans, number of vertebrae and their locations.

Group of vertebrae	Number	Location	Function
1. Cervical vertebrae	7	Neck region	Balancing the head supports head movement and protects the spine

2. Thoracic vertebrae	12	Chest/thoracic region	Attaching to the ribs and forms the chest cavity.
3. Lumbar vertebrae	5	Abdominal region	Bears most of the body weight, supports spinal movement and protects nerves
4. Sacral vertebrae	5	Hip region	Connects the spine to the pelvis, provides stability and support, and helps to widen the pelvis during delivery
5. Coccyx vertebrae	4	Bottom of the spine	Supports sitting and childbirth, serves as an attachment point for muscles, tendons and ligaments

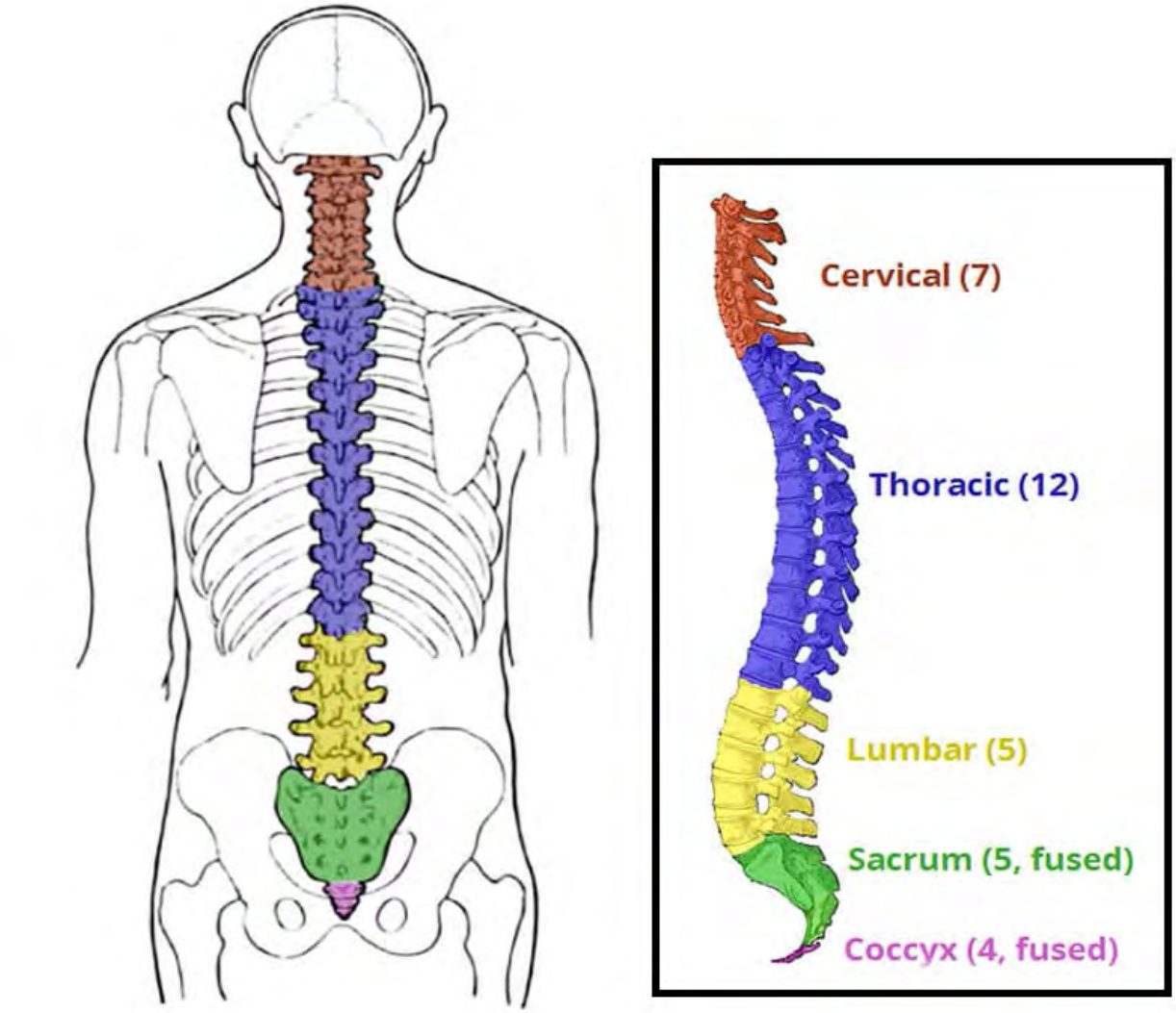


Figure 4.7: Vertebral column of humans

Ribs and Sternum (Breastbone): Ribs are curved bones attached at the back to the thoracic vertebrae and at the front (directly or indirectly) to the sternum.

The rib cage encloses and protects vital organs like the heart, liver and lungs.

There are typically twelve pairs of ribs in humans. These are

i. True ribs (first seven pairs) connect directly to the sternum via costal cartilage.
ii. False ribs (next three pairs) connect indirectly to the sternum.
iii. Floating ribs (last two pairs) are not attached to the sternum.

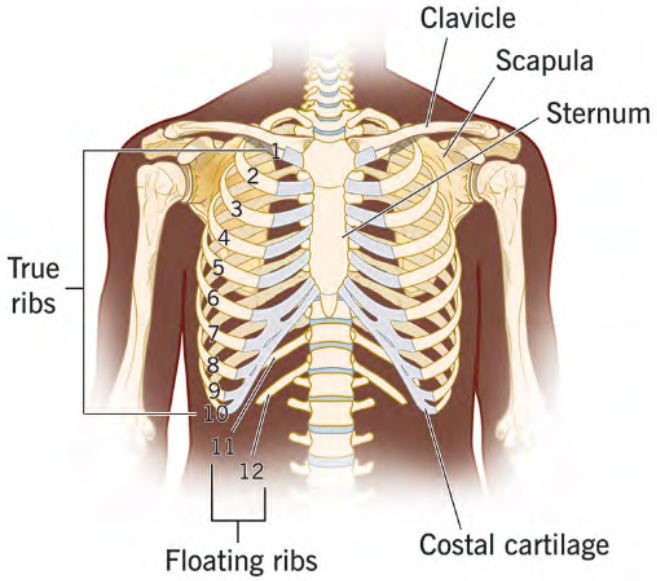


Figure 4.8: Human rib cage.

Appendicular skeleton

The appendicular skeleton consists of the bones of the limbs and their associated girdles (shoulder and pelvic girdles), which attach the limbs to the axial skeleton. They allow for movement and flexibility

Limb girdles

i. Pectoral (shoulder) girdle: Composed of the scapula (shoulder blade) and clavicle (collarbone). It connects the forelimbs (arms) to the axial skeleton.
ii. Pelvic (hip) girdle: Is formed by the fusion of three bones namely, ilium, ischium and pubis. It connects the hindlimbs (legs) to the vertebral column.

Limbs

Each limb has three main sections

i. Upper segment e.g., humerus in the arm, femur in the leg.
ii. Lower segment e.g., radius and ulna in the arm, tibia and fibula in the leg
iii. Terminal segment e.g., hands and feet, including wrist/ankle bones, bones of the palms and feet (metacarpals and metatarsals), bones of fingers and toes (phalanges).

General structure of vertebrae

Structurally, all vertebrae have the following features in common.

1. Centrum
2. Neural arch
3. Neural spine
4. Neural canal
5. Transverse processes
6. Anterior facets (prezygapophyses)
7. Posterior facets (postzygpophyses)

Centrum (Vertebral body): This is solid and cylindrical, in shape, and forms the main body of the vertebra. It bears weight, provides structural support, and serves as the point of articulation with adjacent vertebrae through intervertebral discs. It bears the neural arch and neural spine.

Neural arch: This is an arch which extends from the back of the centrum. Together with the centrum, it encloses the neural (vertebral) canal. The arch forms the roof of the neural canal, which houses spinal nerves and protects the spinal cord from mechanical injury.

Neural spine (Spinous process): This is an outgrowth which projects upward (or backward in upright posture) from the neural arch. It provides a large surface area for the attachment of muscles and ligaments that support the spine and allow movement.

Transverse processes: These are lateral projections which grow from the junction of the neural arch and centrum. They are paired and serve as sites for muscle and ligament attachment. They also articulate with ribs in some vertebrae.

Facets (Articular processes): These are smooth-surfaced projections that extend from the neural arch. They are arranged in anterior (superior) and posterior (inferior) pairs and articulate with adjacent vertebrae. They form synovial joints that permit controlled movement of the spine.

Neural canal/Vertebral foramen: This is a hollowed channel formed by the neural arch and centrum, which runs through all vertebrae. It houses and protects the spinal cord.

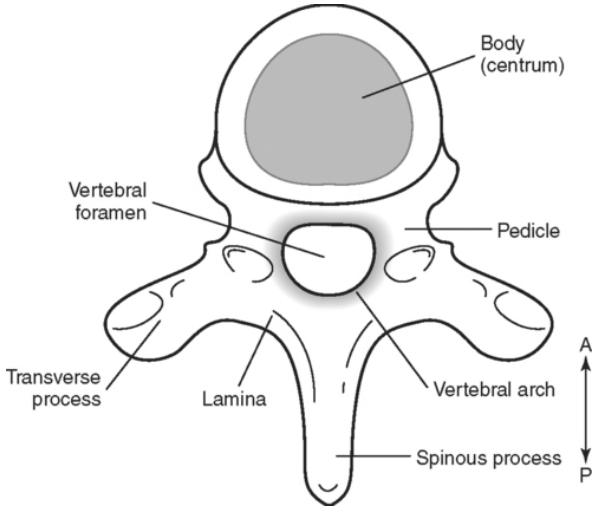


Figure 4.9: General features of a human vertebra

Cervical vertebrae (Neck region)

These are vertebrae located in the neck region. They are seven bones that form the neck, support the skull and enable head movement. The first two cervical vertebrae, the atlas (C_1) and axis (C_2) are unique in structure and specialised to perform their functions.

Atlas (C1): Is the first cervical vertebra, located just beneath the skull. It lacks centrum and has a ring-like structure with large articular facets that articulate with each of the two rounded knobs at the base of the skull. It allows up and down nodding movements of the head, as in "yes."

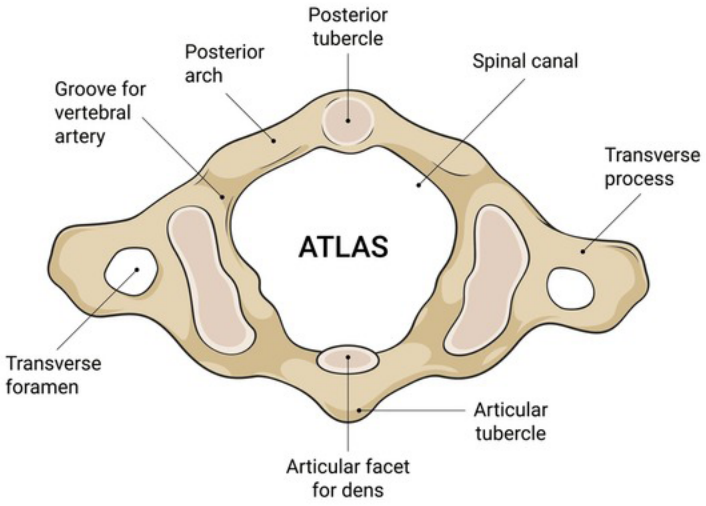


Figure 4.10: Diagram of atlas.

Image source: https://www.shutterstock.com/image-vector/atlas-c1-vertebra-anatomy-diagram-600nw-2506119559.jpg

Axis (C2): Is the second cervical vertebra. It has a peg-like projection called the odontoid process (or dens), which projects upward into the ring of the atlas. This forms a pivot or fulcrum, allowing rotational movement of the head from side to side, as in nodding "no." The odontoid process fits into a groove on the ventral side of the atlas, stabilised by ligaments to allow safe rotation.

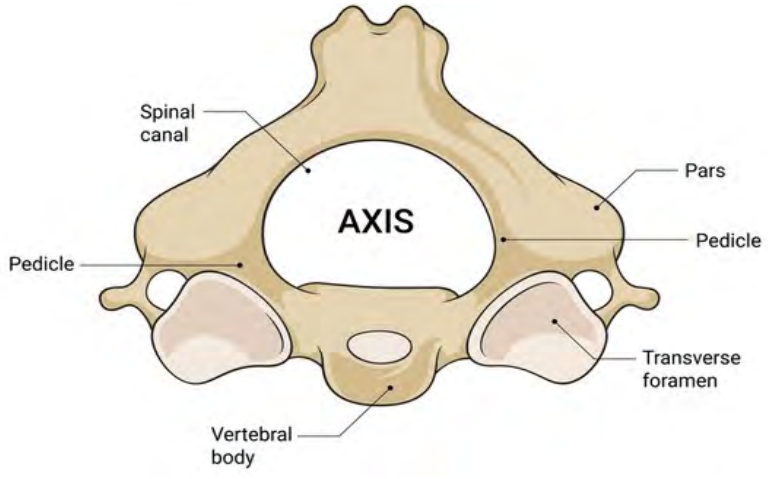


Figure 4.11: Diagram of axis.

Distinguishing Features of Cervical Vertebrae

Cervical vertebrae have features that distinguish them from other vertebrae. These features are:

1. They have a vertebroarterial canal, also called transverse foramen, on each side of the transverse process. This canal allows passage of the vertebral arteries and veins, which supply blood to the brain.
2. They are generally smaller and lighter than other vertebrae.
3. They allow for a wide range of head and neck movements due to their flexibility and specialised structure.

Functions of Cervical vertebrae

1. They support the head and allow its movement.
2. They protect the spinal cord, blood vessels, and nerves in the neck region.
3. They provide attachment surfaces for neck muscles that control head posture and movement.

Thoracic vertebrae

They are located in the thoracic (chest) region of the vertebral column. In humans, there are twelve (12) thoracic vertebrae. This number may be the same or differ on other mammals. Each thoracic vertebra articulates with a pair of ribs, contributing to the formation of the ribcage. They are more robust than cervical vertebrae due to their role in bearing more weight and providing attachment for ribs and muscles.

Features which distinguish thoracic vertebrae from other vertebrae are:

a. **Long neural spine:** Their neural (spinous) process is long and points downward and backward, providing a large surface area for the attachment of thoracic muscles and ligaments.

b. **Facets for articulation with ribs:** Each thoracic vertebra has two sets of facets, which are:

   i. Capitular (costal) facets: Found on the centrum for articulation with the head (capitulum) of the rib.

   ii. Tubercular facets: Found on transverse processes for articulation with the tubercle of the rib. These articulations form synovial joints that allow for limited movement of the ribs during breathing.

c. **Short transverse processes:** These processes are relatively short and stout and bear the tubercular facets for rib attachment.

d. **Heart-shaped centrum:** Centrum is larger and heart-shaped, increasing in size from T_1 to T_{12}, to bear more weight from above.

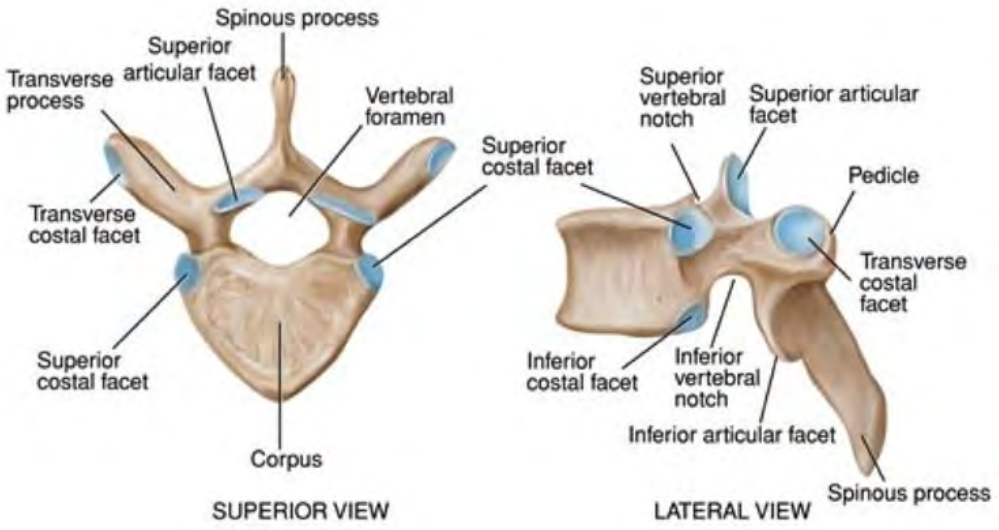


Figure 4.13: A thoracic vertebra

Functions of Thoracic Vertebrae

1. **Support and stability:** The thoracic vertebrae provide strong support for the upper body, including the head, neck, shoulders, and arms.
2. **Protection:** By forming the posterior part of the rib cage, the thoracic vertebrae help protect vital organs, such as the lungs, liver and heart.
3. **Articulation with ribs:** Their structure allows the attachment of ribs, enabling the formation of the thoracic cage necessary for respiration.
4. **Muscle attachment:** The long neural spines and transverse processes serve as anchoring points for back, shoulder, and thoracic muscles, facilitating posture and upper body movement.
5. **Facilitate breathing:** The slight mobility at the rib-vertebrae joints allows for expansion and contraction of the rib cage during inhalation and exhalation.

Lumbar Vertebrae

These are located in the lower back or upper abdominal region, between the thoracic vertebrae and the sacrum. There are five (5) lumbar vertebrae in humans, while the number may differ in other mammals.

Features of Lumbar Vertebrae

1. Thick large centrum: With broad facets for muscle attachment and support.
2. Long, flattened transverse processes: Which serve as surfaces for attachment of strong back and abdominal muscles.
3. Extra accessory process: Which also serves as a point for muscle attachment.

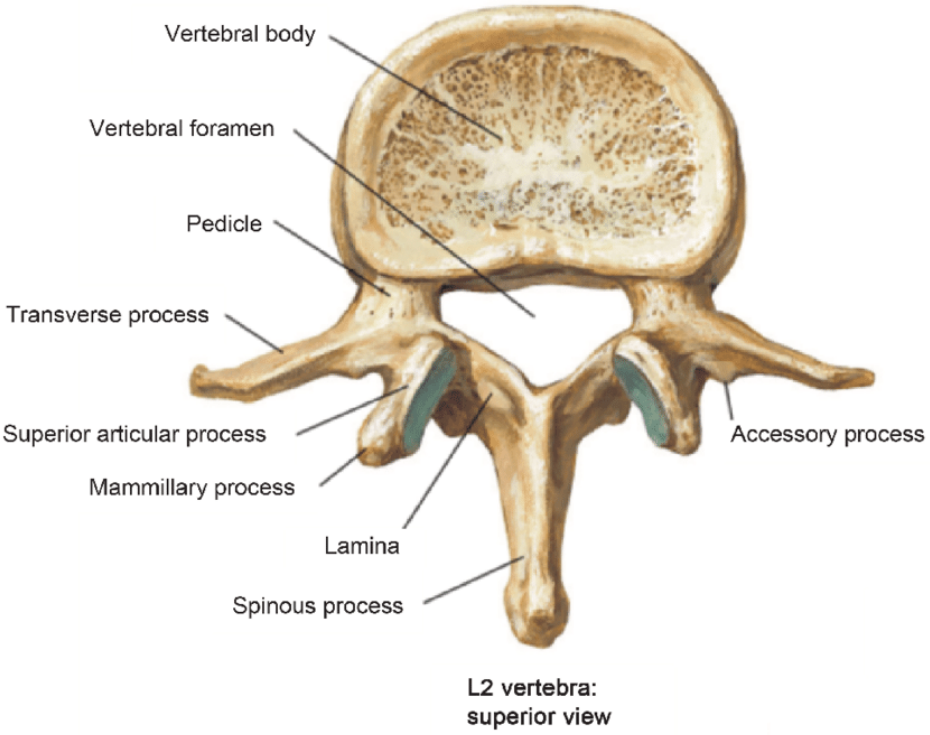


Figure 4.14: A lumbar vertebra

Functions of Lumbar vertebra

1. The large, thick centrum helps to support the upper half of the body, especially the trunk.
2. The broad facets and transverse processes provide ample surface area for muscle attachment, aiding in posture and movement.
3. Lumbar vertebrae absorb stress and shock from activities like walking, lifting, and twisting.

Sacral Vertebrae

There are five (5) sacral vertebrae in humans. These bones are fused together to form a single triangular bone known as the sacrum.

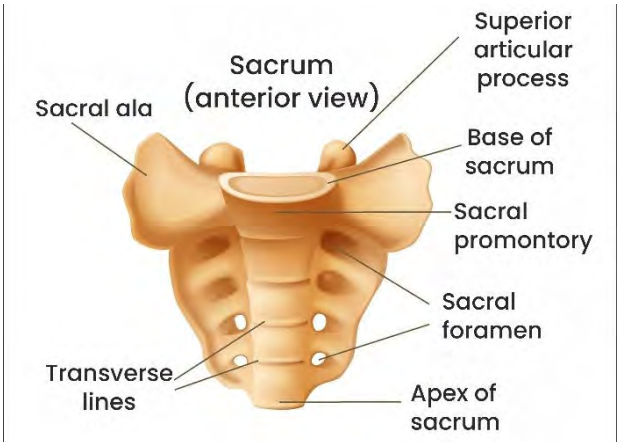


Figure 4.15: A sacral vertebra

Functions of the Sacral vertebra

1. They articulate with the pelvic girdle at the sacroiliac joints, providing a strong, stable connection between the spine and the pelvis.
2. They help to transmit the weight of the upper body to the lower limbs.
3. They form the posterior wall of the pelvic cavity, protecting the pelvic organs.

Caudal vertebrae (Coccyx in humans)

In humans, there are four (4) caudal vertebrae, which are fused to form the coccyx or tailbone. In tailed mammals such as dogs, cats and rats, these vertebrae extend to form their tail. The number of vertebrae forming the tail depends on length of the tail.

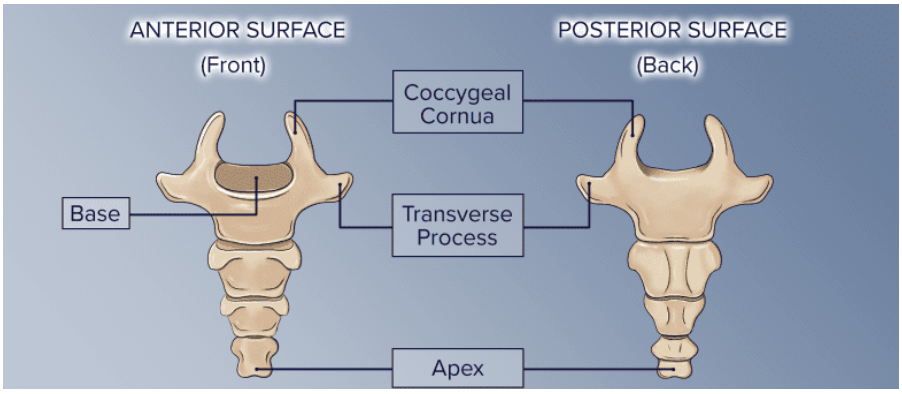


Figure 4.16: Features of a caudal vertebra

Appendicular Skeleton

This consists of the bones of the limbs and their associated girdles (shoulder and pelvic girdles). The girdles attach the limbs to the axial skeleton. Components of the appendicular skeleton are as follows:

Limb girdles

a. **Pectoral (shoulder) girdle:** Composed of the scapula (shoulder blade) and clavicle (collarbone). It connects the forelimbs (arms) to the axial skeleton.

b. **Pelvic (hip) girdle:** Is formed by the fusion of three bones namely, ilium, ischium and pubis. It connects the hindlimbs (legs) to the vertebral column.

Limbs

Each limb has three main segments:

a. **Upper segment:** Humerus in the arm, femur in the leg.

b. **Lower segment:** Radius and ulna in the arm, tibia and fibula in the leg.

c. **Terminal segment:** Hands and feet, including wrist/ankle bones, bones of the palms and feet (metacarpals and metatarsals, respectively), bones of fingers and toes (phalanges).

Functions of appendicular skeleton

1. **Movement**
   a. Locomotion: The lower limbs are specialized for stability and movement like walking and running.
   b. Object manipulation: The upper limbs are designed for a wide range of motion, enabling humans to grasp, lift, and manipulate objects.
   c. Leverage and support: It provides leverage for muscles and supports the limbs, allowing for controlled and efficient movement.
2. **Muscle attachment:** The bony surfaces within the appendicular skeleton serve as attachment sites for muscles, which are essential for any form of skeletal movement.
3. **Limb support:** The pectoral (shoulder) and pelvic (hip) girdles are crucial components that connect the upper and lower limbs to the axial skeleton, anchoring them to the body's trunk.
4. **Other skeletal functions**
   a. Cell, fat and cartilage production: The red bone marrow within the appendicular skeleton produces red blood cells while stem cells in the yellow bone marrow may develop into cartilage, fat, or bone cells.
   b. Mineral homeostasis: These bones store and release essential minerals into the bloodstream as needed, helping to maintain the body's mineral balance.

Pelvic Girdle (Hip Girdle)

The pelvic girdle is made up of two fused halves, joined at the front by the pubic symphysis. Each half consists of the ilium, ischium and pubis. These bones encircle a large opening called the obturator foramen, through which nerves and blood vessels pass.

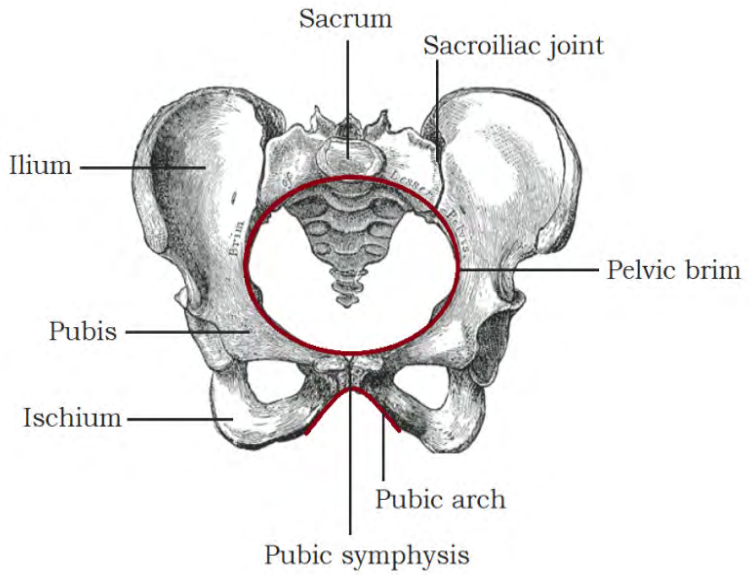


Figure 4.17: Pelvic girdle

Functions of the pelvic girdle

1. Supports the weight of the body.
2. Protects internal organs, especially the female reproductive system.
3. Articulates with the sacrum and the head of the femur at the acetabulum to form the hip joint.

Limbs

Mammals have two pairs of limbs. These are:

a. Forelimbs (upper limbs in humans)
b. Hindlimbs (lower limbs in humans)

The fore and hind limbs are built on a basic pentadactyl plan, which consists of five digits (fingers and toes). They are, therefore, known as pentadactyl limbs.

The forelimb is divided into five major parts as follows

a. Humerus: Is a long bone of the upper arm, articulating with the scapula at the shoulder joint and the radius/ulna at the elbow.
b. Radius and Ulna: Are two bones of the forearm. The ulna is usually longer and forms the hinge joint at the elbow. The radius allows for rotation of the forearm (pronation and supination).
c. Carpals: They are eight to nine small bones forming the wrist. They articulate with the radius/ulna above and metacarpals below.
d. Metacarpals: They are five long bones forming the palm of the hand. They articulate with the carpals and the phalanges.
e. Phalanges (digits): Are bones of fingers and toes. The thumb, which is the first digit on the hand, has two phalanges while the other four digits each have three. Each phalanx may end in a nail or claw, depending on the species.

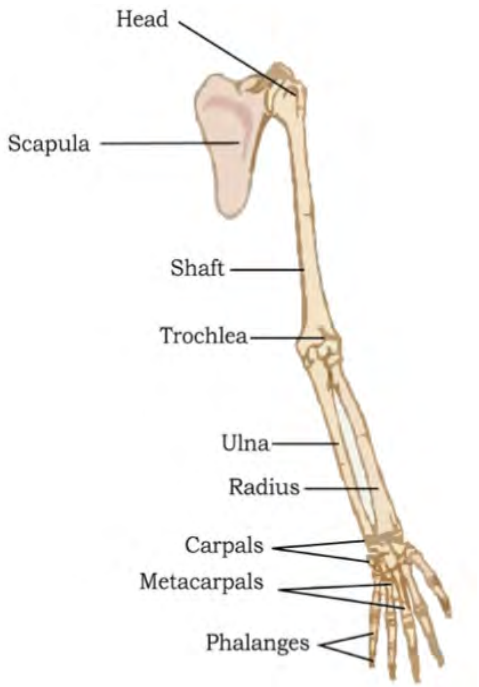


Figure 4.18: A human forelimb.

Hind limb (Lower limb of humans)

Each hind limb is divided into five (5) regions namely

a. Femur: Is a long, single bone in the upper hind limb (thigh). It articulates with the acetabulum of the pelvic girdle to form the ball and socket joint at the hip.

b. Tibia and fibula: This pair of bones makes up the shank of the hind limb. The tibia is longer than the fibula. In most mammals, the lower end of the tibia and fibula are fused together while the upper end of the fibula is free.

c. Tarsals: These are bones of the ankle, numbering nine (9). They are small and irregularly shaped. The longer tarsals fit into the tibia and fibula to form the ankle joint. The tarsals also articulate with the metatarsals of the foot.

d. Metatarsals: There are five of them, which are comparatively longer than the tarsals. They make up the bones of the foot and articulate with the tarsals and the phalanges.

e. Phalanges or digits: These are bones of the toes, numbering five (5) in humans.



Figure 4.19: A human hindlimb.

Activity 4.4 Investigating Functions of the Human Skeleton

Aim: To understand how the various parts of the skeleton work in coordination.

What to do

1. Watch a video by the following link: https://youtu.be/f-FF7Qigd3U
2. Fall into ten groups with three to four learners in each group. Two groups will investigate each of the following parts of the skeleton: Skull, Vertebrae, Ribs and sternum, Upper limbs and lower limbs.

3. After watching the video and with further research, write down the functions of each part of the skeleton named above.
4. Compare your findings with those of your sister group.

Discussion: Compare the functions of your part of the skeleton with those of other parts and establish how the various parts work together to coordinate the activities of the skeleton.

Each group should prepare a map of the coordinated functions and present it for class discussion and critique, after which you arrange them for a gallery walk.

Key question: How effective is the collaboration between the axial skeleton and appendicular skeleton?

STRUCTURE AND FUNCTION OF THE MOVEMENT OF MUSCLE TISSUES

Muscle tissue is a special kind of body tissue that helps us move. It allows us to walk, run, lift things, breathe and even pump blood through our hearts.

Muscles work by contracting and relaxing, which creates movement in different parts of the body. Each type of muscle has a unique structure that helps it to do its specific job.

By learning about how muscle tissue is built and how it works, we can better understand how it contributes to movement. It's important to explore its types, structure, organisation, and mechanism of action. Muscle tissue exists in three main forms: skeletal, cardiac and smooth. Each adapts to different roles in the body's movement and function.

Note

- Muscle tissue contracts to move bones.
- Joints connect bones and allow movement.
- Nerves send signals to muscles, which pull bones to create movement.
- Structure and function of the movement of muscle tissue

Muscles

Muscle tissue is a fundamental type of tissue composed of cells that contract to create movement in the body and within organs. It enables both voluntary and involuntary actions like walking, pumping blood, and digesting food.

There are three types of muscles in the human body. These are the Smooth/Visceral, Skeletal, and Cardiac

1. **Smooth (Visceral)** muscle: A smooth muscle tissue is made up of long, spindle-shaped cells. Each cell has one nucleus. These muscles are found in the walls of the alimentary

canal (like the stomach and intestine), the uterus, blood vessels, and the excretory system (like the bladder).

The activities of smooth muscles are controlled by the involuntary nervous system and not by our conscious minds. Smooth muscles do not get tired quickly, so they can keep working for a long time without resting.

2. **Cardiac muscle**: Cardiac muscle is located only in the walls of the heart. It is capable of contracting and relaxing rhythmically throughout a person's life without becoming fatigued. Cardiac muscle is described as myogenic, which means that its contractions are initiated by the muscle itself rather than by the nervous system, although the nervous system can influence the rate of contraction.

   The fibres of cardiac muscle are striated (striped in appearance) and are connected to each other by cross-links, forming an interconnecting network. Each fibre is uninucleate, meaning it contains a single nucleus.

3. **Skeletal Muscles:** These are attached to two or more bones and are responsible for providing different types of skeletal movements. They are striated, but unlike cardiac muscle, their bundles of fibres are not interconnected. Each muscle fibre contains many nuclei (multinucleate).

   One end of a skeletal muscle (the origin) is attached to an immovable bone, such as the scapula, while the other end (the insertion) is attached to a movable bone, such as the radius. Skeletal muscles are controlled by the nervous system and can be moved voluntarily, so they are known as voluntary muscles. They are able to contract and relax to produce movement, but they become fatigued quickly. The ends of skeletal muscles form tendons, which attach the muscles to bones.

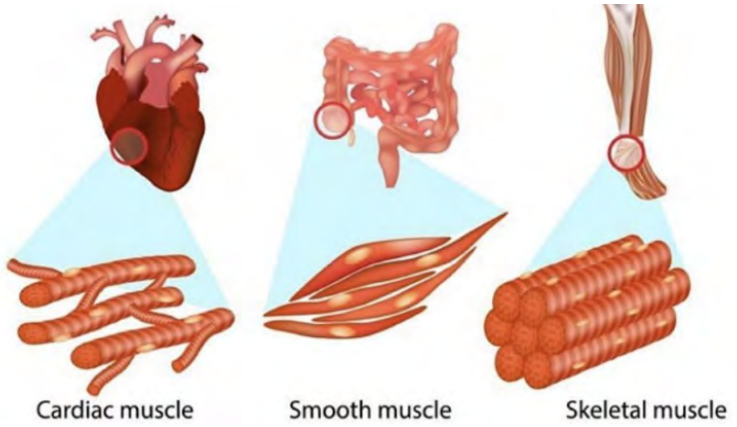


Figure 4.20: Muscle tissues

Activity 4.5 Muscles Match

Aim: To identify the types of muscle and their location in the body

What you need

- Play-dough/clay to mould muscle

- Cut out pictures of skeletal, smooth and cardiac muscle
- Worksheet
- Blank outline of the human body diagram
- Colour pencils/Crayons/paper sticker

What to do

1. Observe the model or pictures of the three muscles discussed
2. Write down your answers to fill in your muscle table.
   a. What does it look like?
   b. Where is it found in the body
   c. What does it do?
3. Take your blank human body diagram
4. Use the colour pencil/ crayon /stickers to show where each muscle type is found.
   a. Red for skeletal muscle (arms, legs, etc.)
   b. Blue for smooth muscle (stomach, intestine)
   c. Purple for cardiac muscle (hearts)
5. In your group, choose one type of muscle
6. Act it out or create a quick movement to show
   a. where it is
   b. What it does
   c. if it moves on its own or if you control it.

JOINT

A joint is a junction between two or more bones. It may be immovable, slightly movable or freely movable.

1. **Immovable joint:** An immovable joint, also known as synarthrosis, is a joint where bones are connected by dense fibrous connective tissue or cartilage, allowing for little to no movement. Immovable joints provide strength and stability. A typical example of immovable joints are the sutures in the skull.
2. **Slightly movable joint** (Cartilaginous joint): This type of joint allows for limited movement, which provides both stability and flexibility. Its bones are connected by cartilage. Examples are joints between vertebrae, two pelvic bones and where ribs connect to the breastbone.
3. **Movable/Synovial joint:** This is a joint that allows for a wide range of motion between bones. Movable joints are formed by bones which are not in direct contact with each other. The bones are held loosely together by ligaments and muscles. The entire

joint is enclosed in Synovial membrane, which secrets Synovial fluid to lubricate the movement of one bone with another. This allows for a wide range of motion. The articular surface of each bone is covered with hyaline cartilage, to act as shock absorber. Movable joints are classified on the basis of the degree of movement allowed. The various types of movable joints, in the human body, are pivot joint, ball and socket joint, hinge joint and gliding joint.

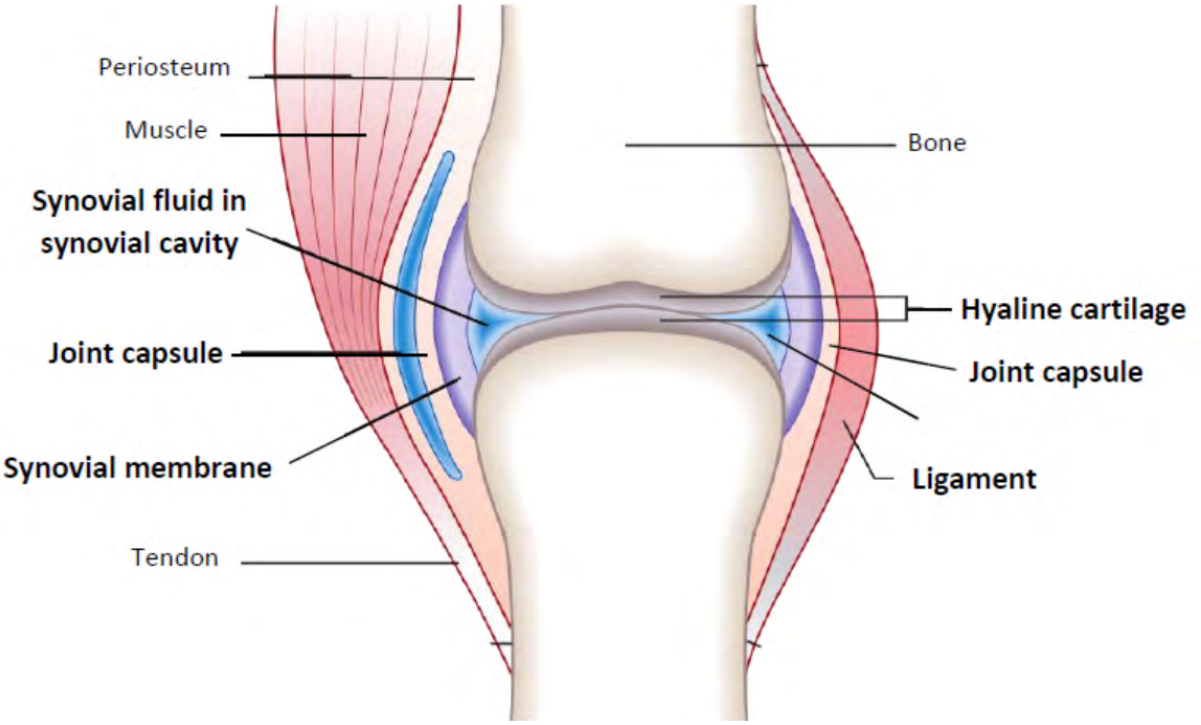


Figure 4.21: Synovial joint

Types of Movable Joint

1. **Ball and socket joints:** They allow movement in more than one plane (rotation, flexion, adduction and abduction movements). They are so-called because a ball-shaped end fits into a socket. Examples are the shoulder joint (humerus in the scapula) and the hip joint (femur in the pelvis).

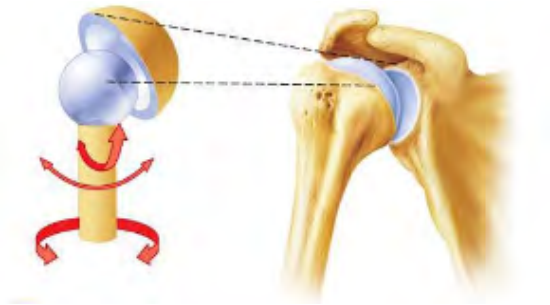


Figure 4.22: Ball-and-socket joint at the shoulder

2. **Hinge joint:** This joint allows movement in only one plane. Examples are the elbow joint, knee joint and joints in the phalanges. At the elbow, the forearm can be raised towards the shoulder in a hinge-like movement just the working of a door hinge. In a similar hinge-like manner, the knee joint causes the leg to be bent backward.

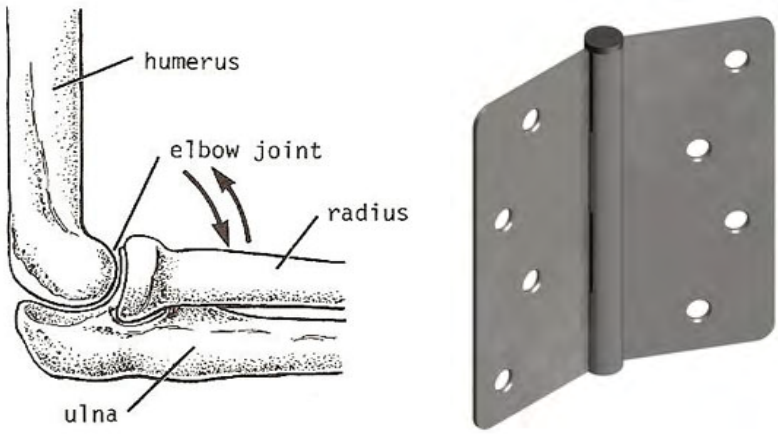


Figure 4.23: Hinge joint at the elbow

3. **Gliding Joint/Plane joint:** It allows for small, sliding or gliding movements between the flat or nearly flat surfaces of two bones. These joints are essential for stability and fine movements. They are found in the carpals of the wrist, the tarsals of the ankle, and the facet joints of the spine.



Figure 4.24: Gliding joints at wrist and ankle

4. **Pivot joint:** This type of synovial joint allows for rotation around a single axis, where a rounded bone rotates within a ring-shaped structure of bone and ligaments. Key examples in the human body include the atlantoaxial joint between the atlas and axis which permits "yes" nodding and "no" nodding, respectively; and the radioulnar joint in the forearm, which permits the hand to twist.

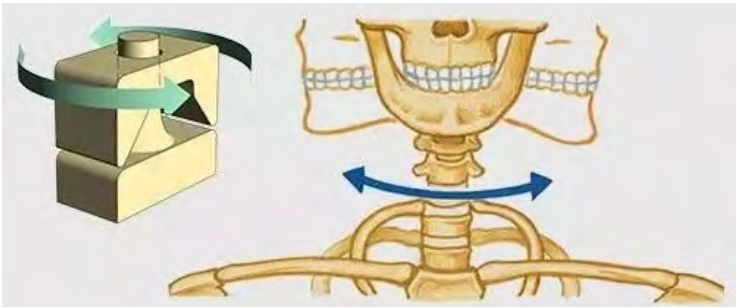


Figure 4.25: Pivot joint in the neck

Key question: What is the effect of injury to a joint on the whole body?

Activity 4.6 Build and Demonstrate Types of Joints

Aim: To create simple models of different types of joints and use them to demonstrate how each joint allows specific movements.

What you need

- Rubber bands
- Cardboard
- Straws
- Paper fasteners (split pins)
- Scissors
- Glue or tape
- Markers (optional, for labelling)

What to do

1. Form small groups (3–5 learners per group).
2. Build models to represent the following joint types:
   a. Hinge joint (e.g., elbow or knee): Use cardboard and paper fasteners to create a model that moves in one direction.
   b. Ball-and-socket joint (e.g., shoulder or hip): Use a ball made of paper or rubber and a socket from cardboard or a bottle cap to allow rotation in many directions.
   c. Pivot joint (e.g., neck): Use straws or rods fixed in a way that allows rotation around a point.
3. Demonstrate each model to another group in the class, showing the type of movement allowed by that joint.
4. Explain the function of each joint type using your model (e.g., "The hinge joint only allows back-and-forth motion like a door").

Activity 4.7 Identifying Joints In The Body

What to do: The table below shows parts of the body and their corresponding joint. Copy and complete the table.

Part of the body	Name of the joint found there
1. Between vertebrae	
2.	Gliding/Planar joint
3.	Ball-and-socket joint
4. Between cranial bones	
5.	Hinge joint
6. In phalanges	
7. Between radius and ulna	
8.	Pivot joint

MOVEMENT OF THE ARM

"Left, right, left, right, swing your arms!!!" You must remember your teacher when he/she was training you for the Independence Day march past a few years ago. What facilitates the movement of the arms? Let us delve into this.

The arms move through the action of two important muscles. These are

1. **The Biceps** muscle, also called the flexor, is located at the front of the upper arm.
2. **Triceps muscles**, also known as the extensor, are located at the back of the upper arm.

These two types of muscles work by opposing each other (in an antagonistic manner). Hence, they are always disagreeing with each other. When the biceps contract (shorten), under nervous stimulation, the triceps relax (lengthen). This pulls the radius upward which bends the arm at the elbow (a movement called flexion).

On the other hand, when the triceps contract, the biceps relax. This pulls the ulna downward through the olecranon process, straightening the arm (a movement called extension).This antagonistic muscle action, by the biceps and triceps, is essential for coordinated limb movement, allowing humans to perform tasks such as lifting, pushing, pulling, and throwing. It also helps maintain joint stability and prevents sudden or jerky movements.

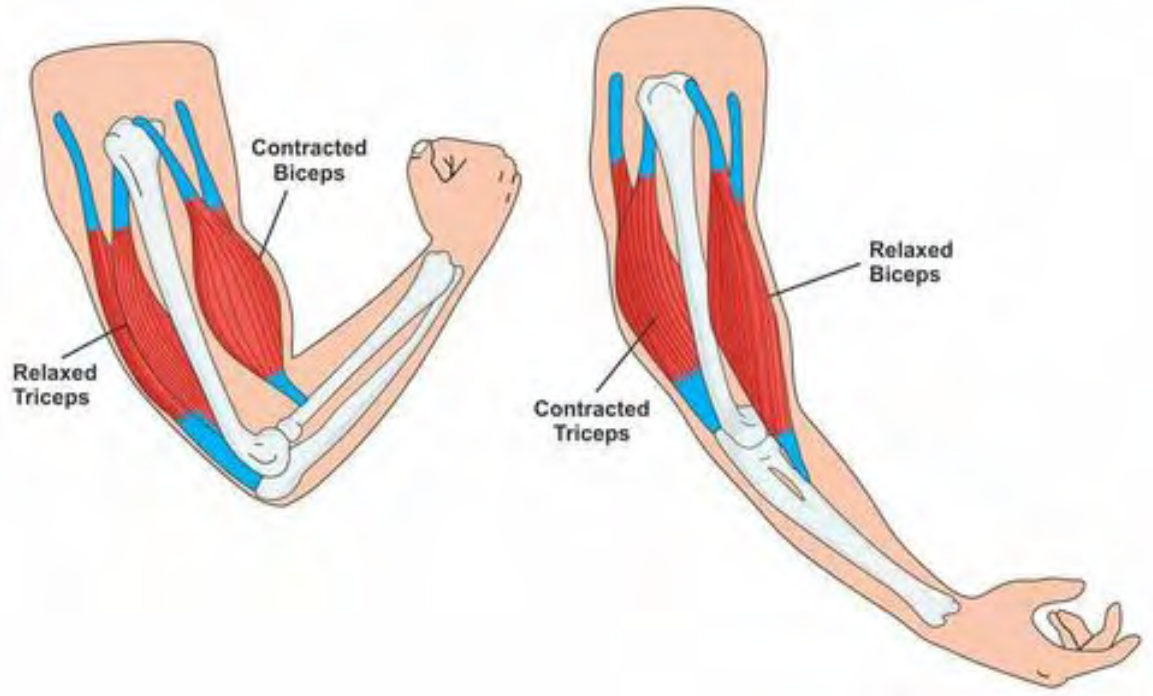


Figure 4.26: Opposing movements of biceps and triceps

Activity 4.8 Demonstrating Flexion And Extension

Aim: To help understand the opposing actions of one's biceps and triceps.

What to do

1. Place one hand on the front of your other arm's upper arm.
2. Bring your hand towards your shoulder.
3. Feel your biceps.
4. Now, place the same hand on the back of the same upper arm
5. Straighten your arm completely.
6. Feel your triceps.
7. Repeat the activity in pairs with each other.

Discussion: Discuss your observations among yourselves and share with the rest of the class.

Key question: What do you think would be the effect on arm movement if biceps and triceps did not oppose each other?

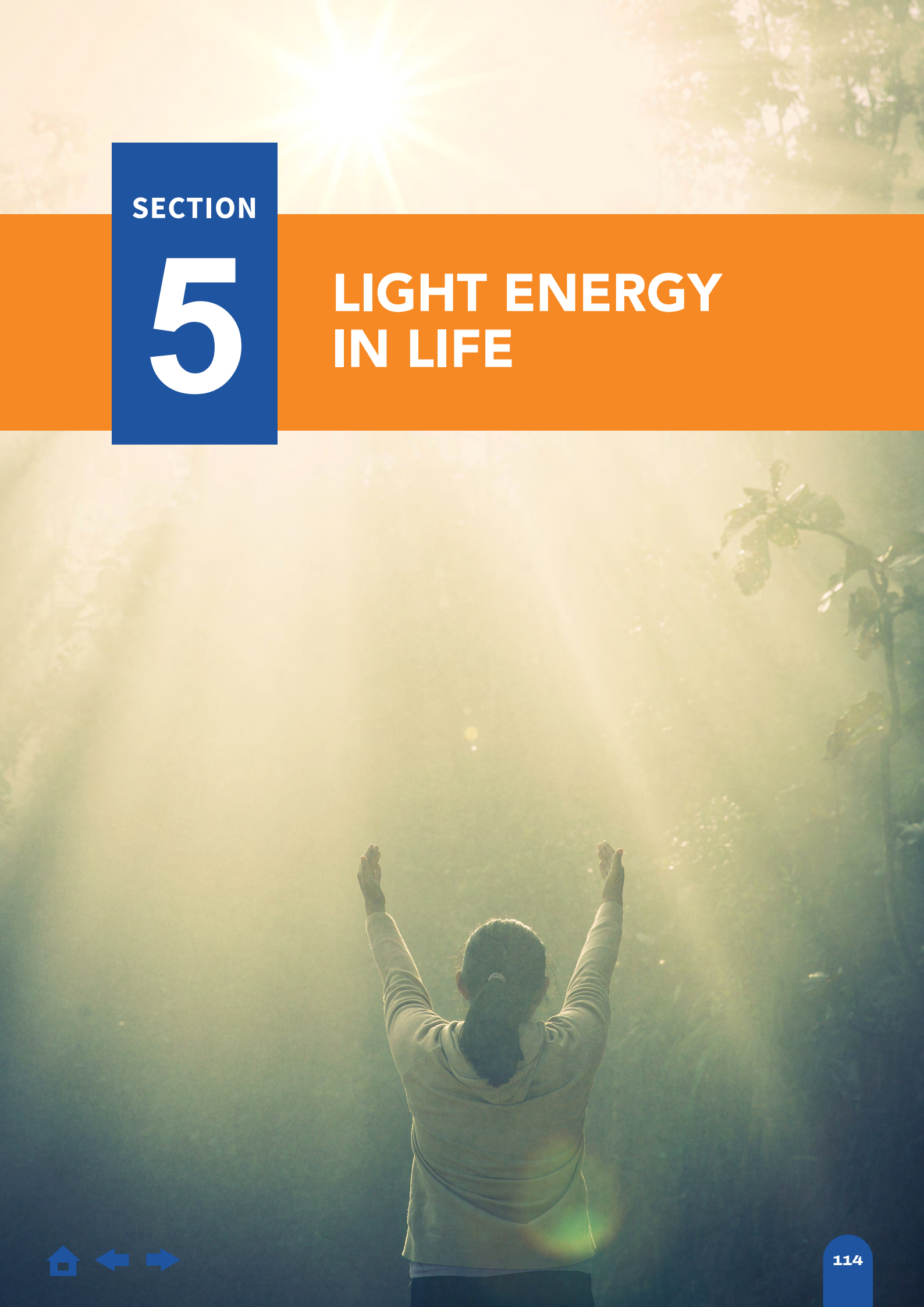
REVIEW QUESTIONS

1. Study and compare the three different types of skeletons found in animals. Create a comparison that shows how they are similar and different. Your response should;
   - give at least two examples of organisms for each type.
   - describe the skeletal material involved.
   - give advantages and limitations of each type in terms of movement and protection.
   - provide information on how each supports survival in different habitats.
2. Describe how the biceps and triceps muscles work antagonistically to move the arm.
3. Compare and contrast the actions of hinge joints and ball-and-socket joints using real-life movements (e.g., kicking vs. waving).
4. Design and explain a model that shows how antagonistic muscles and hinge joints work together to produce controlled limb movement.

SECTION

5

LIGHT ENERGY IN LIFE



VIGOUR BEHIND LIFE

INTRODUCTION

Light energy is a type of energy that moves in waves and helps us see the things around us. In this topic, you will learn what light energy is, where it comes from, and how it behaves when it hits different objects. You will find out how light is used in our daily lives, like in seeing, taking pictures, using solar panels, and even sending messages through fibre optics. You will also discover how tools like mirrors and lenses change the direction of light. These tools help us form images in devices such as cameras, eyeglasses, telescopes, and microscopes.

KEY IDEAS

- Mirrors work by reflecting light rays that strike their surface, allowing us to see images of objects placed in front of them. Without light, mirrors cannot form any image, as there would be nothing to reflect.
- Light is a form of energy that travels in straight lines, can be reflected, refracted, or absorbed, and does not require a medium to move. Its properties help us see and understand the world around us.
- Light enables us to see, powers solar panels, helps plants grow through photosynthesis, and is essential for technologies like cameras and fibre-optic communication.
- Mirrors are used in devices such as periscopes and shaving mirrors, while lenses are vital in spectacles, cameras, microscopes, and telescopes to focus and form images.
- When light passes through a lens, it bends (refracts), causing the rays to converge or diverge. This property of lenses is used to focus light and produce clear images in many optical instruments.

LIGHT AND ITS PROPERTIES

Lenses and Mirrors in Relation to Light Energy in Life

Can you imagine a day when the sun will fail to rise? Of course, this happens in the polar regions of the Earth at certain times of year. However, those of us living near the equator do not have that experience. You can guess how difficult and costly it would be to live without the sun, which is the main source of light and warmth. Light is a very important form of energy which gives rise to other energy forms and phenomena, both natural and artificial. Let us now delve into the concept of light.

Light and Its Properties

Light is a form of energy that is visible and enables us to see the world around us. It is one of the types of radiation in the electromagnetic spectrum and is made of basic particles called photons. The photons are capable of travelling through a vacuum, so light does not need any other medium to carry its particles along. The study of light, in relation to what it can do and the instruments that depend on it, is known as optics.

Properties of Light

1. **Rectilinear propagation:** Light travel in a straight line in the same medium.
2. **Reflection:** Photons bounce off when they hit a surface which they cannot pass through.
3. **Refraction:** Photons increase their speed when they enter a less dense medium and decrease their speed when they enter a denser medium. This causes light to bend to follow a different path when they move from one medium into another.
4. **Absorption**: Photons may get trapped in materials on which they cannot bounce off or pass through. Materials with a dark surface absorb light more than those with light-coloured surfaces.
5. **Finite speed:** Speed of light in vacuum (or in air) is about 300,00km/s. This speed decreases in a medium which is denser than air, such as water or glass.
6. **Colour:** Visible Light is composed of the following colours: Red, Orange, Yellow, Green, Blue, Indigo and Violet (ROYGBIV). These colours can be seen as the rainbow when it appears in the sky.

Activity 5.1 To demonstrate that light travels in straight line

Aim: To show that we see things when light travels, in straight lines, from those things into our eyes.

What you need

- Torch or candle as a source of light.
- Cardboard with a pinhole in each, in the middle.
- White screen or observer's eye.

What to do

1. Place three cardboard pieces with holes in a straight line.
2. Light the torch or candle.
3. Place the lit torch or candle in front of the hole in the first cardboard and let it shine through the other holes towards a screen/observer's eye..
4. Observe the light path.
5. Move one cardboard out of line and observe what happens.

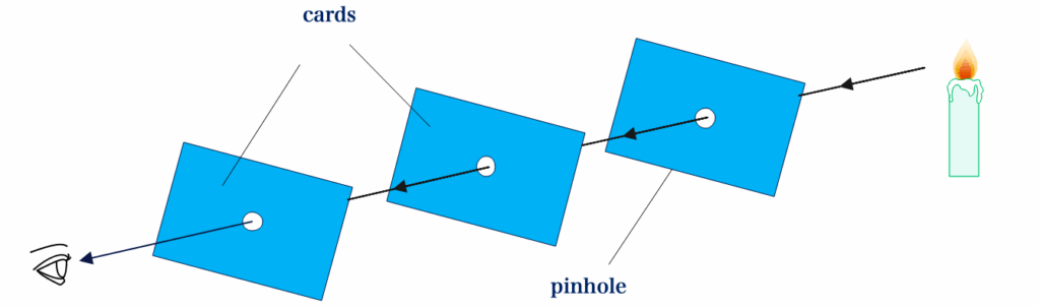


Figure 5.1: Light travels in a straight line

Safety precaution(s)

1. When using a candle, make sure there is no combustible material near you, to avoid setting the environment ablaze.
2. Place the source of light and cardboards on a levelled surface, for alignment.

MIRROR

A mirror is an optical device that reflects light. It is usually made of glass, with its reflective surface coated with a thin layer of metal such as silver or aluminium. The other surface is painted to make it opaque. When light from an object hits a mirror and is reflected, the reflected light enters our eyes, enabling us to see the object.

Types of mirrors

There are many types of mirrors. Three of these are

1. Plane mirror
2. Concave/converging mirror
3. Convex/diverging mirror

Concave and convex mirrors are also known as curved or spherical mirrors.

Each type of mirror behaves differently with light and is used in various practical applications.

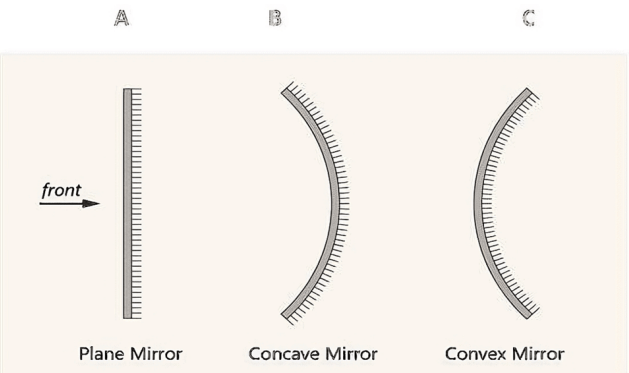


Figure 5.2: Types of mirrors

A mirror is defined as a reflecting surface and can be explained by the laws of reflection which are detailed later in this section.

Terms related to mirrors on reflection of light

1. **Incident ray:** Is the ray of light that hits the mirror surface.
2. **Reflected ray:** Is the ray of light that bounces off after hitting the mirror surface.
3. **Normal:** Is an imaginary line that hits the mirror surface at 90° (perpendicular to the reflecting surface).
4. **Angle of incidence:** Is the angle between the incident ray and the normal with respect to which the incidence occurs.
5. **Angle of reflection:** Is angle between the reflected ray and the normal with respect to which the reflection occurs.



Figure 5.3: Reflection of light.

Plane mirror

It has a flat or plane reflecting surface. It is commonly used in everyday life, such as in barbering shops, cameras, periscopes, microscopes and for decorative purposes.



Figure 5.4: A plane mirror

Reflection of Light in a Plane Mirror

Reflection of light in a plane mirror is called regular or specular reflection. This means that when a number of rays of light are incident on the mirror surface at the same time, they are reflected in the same order and at the angle at which they arrived at the mirror. This process follows the laws of reflection of light which are stated below.

Laws of Reflection of Light

1. The incident ray, reflected ray and normal at the point of incidence, all lie in the same plane.
2. The angle of incidence is equal to the angle of reflection.

These laws mean that when a set of light rays hits a plane mirror surface and bounces off, all three rays, i.e. the incident ray, reflected ray and the normal at the point of incidence, can all be found at the same point in the same plane of the mirror. Also, if a ray of light hits a plane mirror surface at an angle of $\angle i$, then it is reflected at an angle of $\angle r$ such that $\angle i = \angle r$.

How true are the laws of reflection of light? Let us answer this question by performing the following activity. Do it in a group of four members.

Activity 5.2 Verifying the laws of reflection of light

Aim: To explain the laws of reflection.

What we need

a. Plane mirror
b. Drawing board
c. White paper
d. Search pins (4)
e. Protractor
f. Ruler
g. Pencil
h. Small wooden block to hold the mirror upright.

What to do

a. Fix the white paper on the drawing board.
b. Draw a straight line (XY) across the paper and place the mirror strip vertically along this line, supported by the wooden block.
c. Draw a normal (ON) at any point O on XY.
d. Draw an incident ray (AO) at an angle to the normal (e.g., 30°). Fix two pins (P1 and P2) vertically on this line.

e. Looking at the reflection of P1 and P2 in the mirror, fix two more pins (P3 and P4) such that P3, P4, and the images of P1 and P2 are in a straight line.

f. Remove the mirror and the pins. Draw a line (OB) joining the pinpricks P3 and P4 and extend it to O. This is the reflected ray.

g. Measure the angle of incidence (∠AON) and the angle of reflection (∠BON).

h. Repeat for different angles of incidence (e.g., 45°, 60°).

i. Record your observation.

Precautions for accuracy

a. Fix the search pins firmly on the drawing board.

b. Place your eyes at the level of the pins.

c. Ensure there is no parallax between pins 1&2 and 3&4.

Key question

a. Write down your response in your **notebook**.

b. What other precautions would you adopt to ensure accuracy?

Image Formed at a Plane Mirror

A plane mirror forms the image of an object when light rays from the object reflect off the mirror surface according to the law of reflection, where the angle of incidence equals the angle of reflection. The reflected rays, if extended backward, appear to originate from a point behind the mirror where they intersect to locate the image formed. An example is illustrated below.

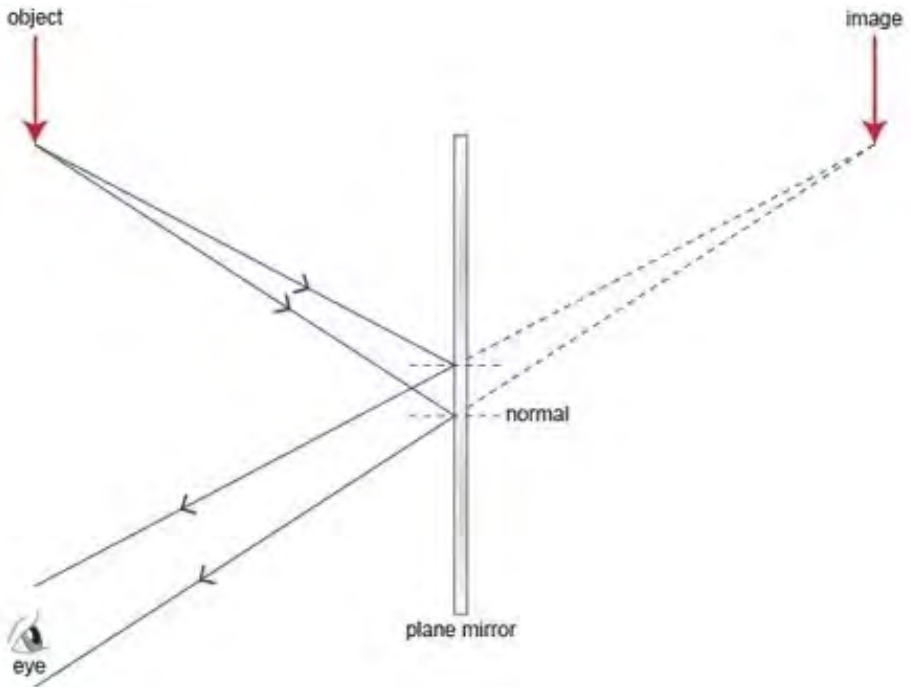


Figure 5.5: Image formed by plane mirror

In the ray diagram above, the incident rays from the object are reflected off the plane mirror and hit our eye. Our brain projects the reflected rays behind the mirror, meaning the light rays do not actually reach the image. It is, therefore, a virtual image.

Now, study the following worked examples on the law of reflection of light.

Characteristics of image formed by a plane mirror

1. **It is virtual:** Formed by backward extension of reflected rays (do not actually meet). Such an image cannot be captured on a storage device.
2. **It is erect/upright:** Is oriented in the same direction as the object.
3. **Same size:** Size of the image formed is the same as size of the object. For instance, your height is the same as the height of your plane mirror image
4. **Laterally inverted**: The right side of the image corresponds with the left side of the object and vice versa. For instance, if you raise your right hand in front of a plane mirror, your image raises its left hand.
5. **Same distance:** Image is the same distance away from the mirror, behind it, as the object in front of it. If you stand one metre away from the mirror, your image also stands at one metre away from the mirror

Worked examples (solutions in Annex 5.0 on page xxxxx)

5.1. A light ray strikes a plane mirror at an angle of incidence of 35°. What is the angle of reflection?

5.2. A ray strikes a mirror at an angle of incidence of 40°. What is the total angle between the incident ray and the reflected ray?

Uses of Plane Mirrors

Plane mirrors are used for variety of applications. The detailed applications of plane mirrors are mentioned below.

1. **Periscope:** Submarines use periscopes to see objects on the water's surface. It is impossible to bend light rays since they move in straight directions, although they can be reflected. The plane mirrors of a periscope adjust the direction of light rays so that the item can be seen by the submarine's viewer.
2. **Telescope:** A telescope is used to observe distant objects in the solar system, such as planets. Telescopes are classified into two types. A set of lenses is used in a refracting telescope. Plane mirrors are used in conjunction with spherical mirrors in reflecting telescopes.
3. **Saloon:** We can create unlimited images by installing plane mirrors parallel to each other. This allows the customer to view both the front and rear of a person.
4. **SLR cameras:** Single-lens reflex (SLR) cameras use plane mirrors to redirect light from the lens allowing photographers view exactly what is to be captured.
5. **Microscopes**: Plane mirrors are used to reflect light onto the specimen to brighten it.
6. **Surveillance systems:** Plane mirrors that are placed in a certain way can help people keep an eye on places that they cannot see directly. This can be useful in surveillance systems where people want to observe things without being noticed.

7. **Education and science:** Plane mirrors are educational tools in science classrooms, to demonstrate the principles of optics and light reflection to learners.
8. **Navigation:** In navigation tools such as sextants, plane mirrors aid in celestial navigation by reflecting light from celestial bodies, assisting sailors and navigators in determining their position relative to the horizon and celestial objects.
9. **Decorative purposes:** Plane mirrors are used in interior design to create illusions of space by reflecting light and enhancing the appearance of rooms.

Concave mirrors (converging mirrors)

A concave mirror is a mirror whose reflecting surface curves inward, giving an impression of looking into a hollow or cave-like surface.

Properties of Concave Mirrors

1. They bring light rays to a single point (focus) after reflection from the mirror. They are, therefore, called converging mirrors.
2. It can form real and virtual images, which may be smaller or larger than the object or have same size as object, depending on the distance of the object from it.
3. The closer an object gets to the mirror, the bigger is the image formed. The image gets smaller as the objects moves away from the mirror.

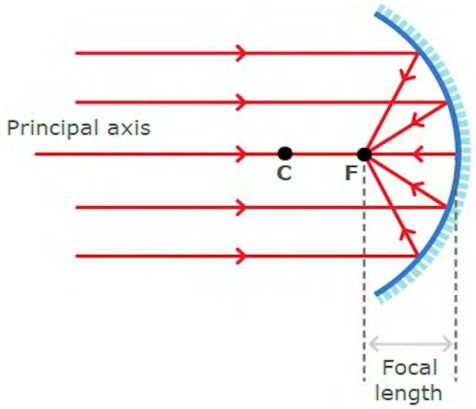


Figure 5.6: Reflection of light on concave mirror

Uses of Concave Mirrors

1. **Shaving mirrors:** When held close to the face, they produce a magnified and upright image, making it easier to see details.
2. **Ophthalmoscopes:** Used to construct ophthalmoscopes which are instruments that doctors use to examine the interior of the eye.
3. **Astronomical telescopes:** Used as objectives in astronomical telescopes to collect and focus light from distant celestial bodies. They must be large enough for this purpose (with a diameter of five metres (5m) or more).
4. **Torchlights, headlights and searchlights:** Used as reflectors to produce strong and focused parallel beams of light in car and aircraft headlights, torchlights and searchlights.

5. **Solar furnaces and ovens**: Large concave mirrors are used in solar heating devices to concentrate sunlight at a single focal point to generate intense heat. This heat is used for cooking, baking ceramic materials or melting substances such as metals.



Figure 5.7: Concave mirror for magnification

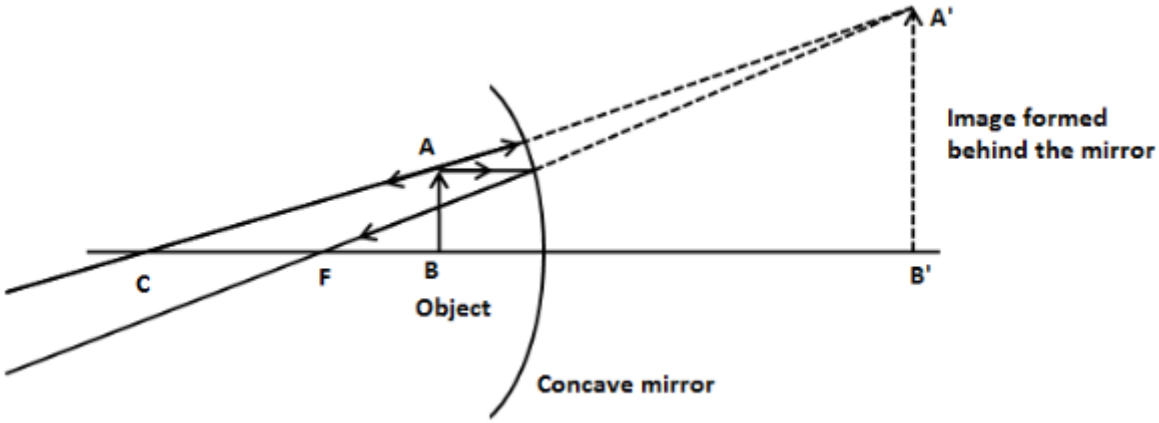


Figure 5.8: Ray diagram of a shaving mirror

Convex mirror

A convex mirror is a type of spherical mirror whose reflecting surface is curved outward, like the back of a spoon. It is also known as a diverging mirror because the light rays that strike its reflecting surface spread out (diverge) after reflection. The diverging rays then, appear to originate from a common point behind the mirror. The point where the diverging rays appear to originate is location of the image, formed of an object, by the mirror.

Characteristics of Convex Mirrors

1. **Spreading of light rays:** They cause light rays to move apart (diverge), after reflection.
2. **Virtual image**: Form virtual images only. Images formed, therefore, cannot be projected on a screen.

3. **Erect/upright image:** Image formed is always erect/upright (has the same orientation as the object)
4. **Diminished/smaller image:** Always form images which is smaller than their objects.

These properties can be demonstrated by observing images of objects formed by the back of a spoon made of stainless (or another shiny metal). The spoon will be observed to be reflecting light falling on it to produce smaller, upright images of whatever objects that happen to be in front of it.

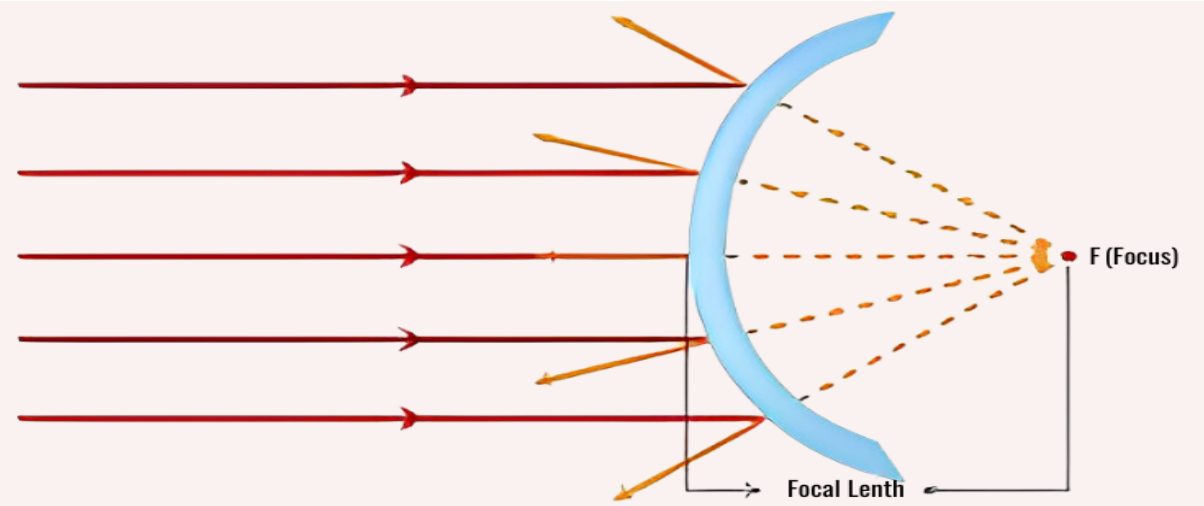


Figure 5.9: Convex mirror diverges light after reflection

Uses of Convex Mirrors

Uses of convex mirrors are based on their ability to capture a wider field of view (as a result of divergence of the reflected light) than other types of mirrors. Also, in addition to being virtual and erect, the images formed are diminished so that more images of objects can be accommodated in the view. These uses are:

1. **Safety and monitoring:** Convex mirrors are installed in sharp curves on highways, large offices, stores, hospitals, and other public buildings to monitor and boost safety by allowing people to see around corners, in hallways and corridors; and to help prevent collisions by providing visibility in blind spots.
2. **Driving mirrors**: Used in vehicles and motorcycles as rear-view and side mirrors to give a wider field of view, helping drivers see more of the road and traffic around them. They also produce virtual, upright and reduced images, allowing more objects to be seen in a small mirror.
3. **Magnifying glass**: Used to make magnifying devices. In industrial applications, two convex mirrors can be placed back-to-back to enhance magnification effects.
4. **Security and surveillance:** Used for security purposes near ATMs, allowing users to see if they are being trailed. They are also widely used in shopping centres or parking areas to improve visibility or monitor suspicious activities.
5. **Street light reflectors:** Used in street lighting systems to help spread light over a wider area, improving coverage and illumination.



Figure 5.10: A convex mirror

Important terms in concave and convex mirrors

1. **Pole (P):** Is the midpoint of the mirror's surface. Object distance, image distance and focal length are measured from the pole.
2. **Aperture:** Is the diameter of the reflecting surface of the mirror. It defines the size of the mirror and the area over which reflection of light occurs.
3. **Principal/Main axis:** Is an imaginary, straight, horizontal line that passes through the pole (P), principal focus (F) and centre of curvature (C). Measurement of angles and lengths are taken with respect to this axis.
4. **Centre of curvature (C):** Is the centre of the sphere from which the mirror surface is taken. It lies on the principal axis, outside the mirror surface. For a concave mirror, it is in front of the mirror; for a convex mirror, it is behind.
5. **Principal focus/Focal point (F):** Is the point on the principal axis where, in a concave mirror, parallel rays converge after reflection and in a convex mirror, where parallel rays appear to diverge from, after reflection.
6. **Focal length (f):** Is the distance from the pole to F.
7. **Radius of curvature (R):** Is the distance from the pole (P) to the centre of curvature (C). It is equal to twice the focal length, i.e., $R = 2f$.

Characteristics of images formed by a concave mirror

The various locations of object, ray diagram, size and nature of image formed are shown in ***Table 5.1***.

Table 5.1: Images formed by a concave mirror

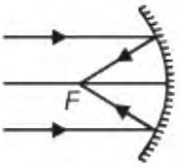
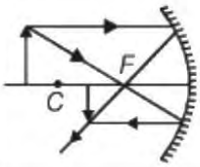
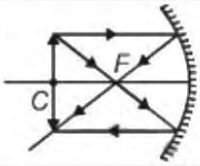
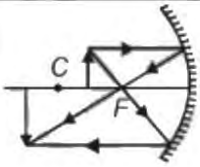
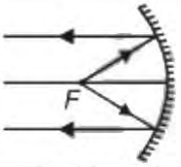
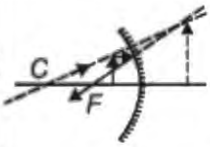
Position of object	Figure	Position of image	Nature of image
1. At infinity		At the principal focus or in the focal plane	Real, inverted, extremely diminished in size
2. Beyond the centre of curvature		Between the principal focus and centre of curvature	Real, inverted and diminished
3. At the centre of curvature		At the centre of curvature	Real, inverted and equal to object
4. Between focus and centre of curvature		Beyond centre of curvature	Real, inverted and bigger than object.
5. At the principal focus		At infinity	Extremely magnified
6. Between the pole and principal focus		Behind the mirror	Virtual, erect and magnified

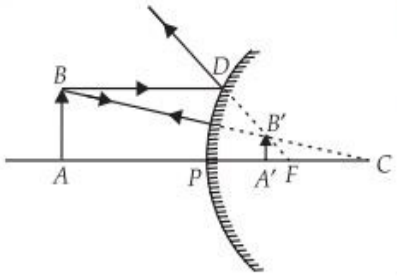
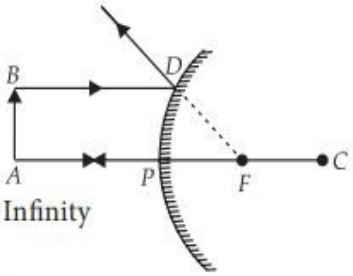
Image formed by a convex mirror

There are two possible positions of the object in the case of a convex mirror. These are

1. When the object is at infinity.
2. When the object is between infinity and the pole of the mirror.

These are illustrated in ***Table 5.2*** below.

Table 5.2: Image formed by a convex mirror

Convex mirror			
Ray diagram	**Object position**	**Image position**	**Nature of image**
(a) 	Between infinity and the pole	Behind the mirror between the focus and the pole	Virtual, smaller and erect
(b) 	At infinity	Behind the mirror at the focus *F*	Virtual, point-sized and erect

Mirror Formula

To solve numerical problems involving spherical mirrors (concave or convex), we use the mirror formula. This formula helps calculate important quantities. These are as follows:

1. Focal length (f)
2. Object distance (u)
3. Image distance (v)
4. Magnification (m)

The mirror formula: $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$

Where:

f = focal length of the mirror.
v = image distance (from the pole).
u = object distance (from the pole).

Sign Convention (Based on the Cartesian System)

1. All distances are measured from the pole (P) of the mirror.
2. Distances measured to the right of the pole (along the direction of incident light) are positive.
3. Distances measured to the left of the pole (against the direction of incident light) are negative.

   The focal length (f) is:

   a. Negative for a concave mirror

b. Positive for a convex mirror

4. The object distance (u) is usually negative (as objects are generally placed in front of the mirror).

The image distance (v) is:

a. Positive if the image is formed behind the mirror (virtual).
b. Negative if the image is formed in front of the mirror (real).

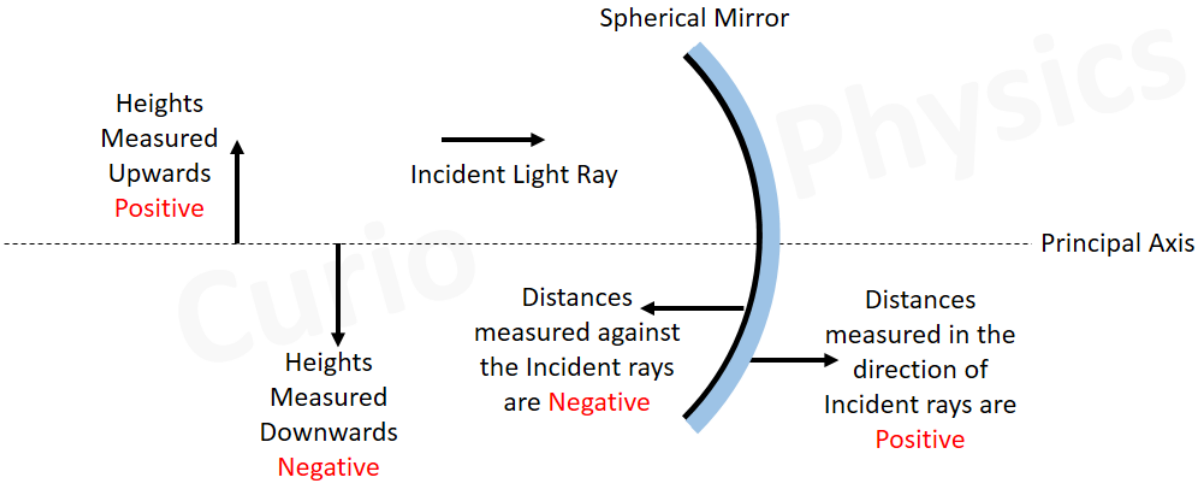


Figure 5.11: New Cartesian convention.

Worked Example

5.3 An object is placed 30 cm in front of a concave mirror. The focal length of the mirror is 15 cm. Find the position and nature of the image.

Solution

By New Cartesian convention,

object distance, $u = -30$ cm
focal length, $f = -15$ cm
image distance, v - ?

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$
$$\frac{1}{-15} = \frac{1}{v} + \frac{1}{-30}$$
$$\frac{1}{v} = \frac{1}{15} + \frac{1}{30}$$
$$\frac{1}{v} = \frac{2+1}{30} + \frac{-1}{30}$$
$$v = -30 \text{ cm}$$

Result

- The image is formed 30 cm in front of the mirror.
- It is real and inverted (because v is negative).
- Same size as the object (since $u = 2f$).

5.3. An object is placed 20 cm in front of a convex mirror. The focal length is 10 cm. Find the position and nature of the image**. Find the solution in Annex 5.0!**

Activity 5.3 Produce a Poster Demonstrating the Applications of Mirrors in Optics

Create a single-sided A4 poster highlighting some of the applications of mirrors in various fields. Use pictures and diagrams to make your poster eye-catching. Try to include a brief summary of how mirrors are used in each context.

Some ideas for fields of optics are:

1. Photography
2. Periscopes
3. Microscopes
4. Driving mirrors

Activity 5.4 The Role of Mirrors in Manipulating Light

Write a single paragraph response to the question 'How are mirrors used to manipulate light and where do we encounter examples of this on a day-to-day basis?'

1. Dear learner, examine the picture below.



Figure 5.23: Using a periscope

The man in ***Figure 5.23*** above is using an optical instrument called a periscope**.**

Key questions

Discuss and write down your response in your notebook.

a. Why is the man using the periscope?

b. How does a periscope work?

Now, let us build the prototype of a periscope and get an understanding of how it works.

Do this activity in your mixed-ability groups.

Activity 5.5 Building a prototype of a periscope

Aim: To understand how two plane mirrors can be arranged to produce total internal reflection in a periscope that can see over or around obstacles.

What you need

- Two small plane mirrors (about 5 cm x 5 cm).
- A rectangular cardboard box or sturdy cardboard sheets (approximately 30 cm long).
- Ruler.
- Pencil.
- Cutter or scissors.
- Glue or tape.
- Protractor (for measuring 45° angles).
- Black paper (optional, to reduce light inside the periscope).

What to do

a. Use a long cardboard box (like a cereal box) or create a rectangular tube using cardboard sheets.

b. Make sure the box is closed on all sides except for openings at both ends.

c. At the top and bottom ends of the box, mark two square holes on the front and back faces. These holes will allow light to enter and exit the periscope.

d. Carefully cut out the marked squares using a pair of scissors or any other cutter.

e. Inside the box, draw lines at 45° angles near both the top and bottom ends.

f. Use a protractor to ensure accuracy.

g. Place one mirror at the top, angled at 45°, facing the top opening.

h. Place the second mirror at the bottom, angled at 45°, facing the bottom opening.

i. Secure the mirrors with glue or tape.

j. Ensure the box is sealed except for the view holes.

k. Optionally, line the inside with black paper to minimise internal reflections.

l. Use your prototype to view over or around an obstacle.

Key question

Discuss and write down your response in your notebook.

a. How convenient is your periscope, especially to those who are short?

b. In what other fields can periscopes be used?

SAFETY MEASURES

What did you do to avoid injury and build a good prototype?

Write them down.

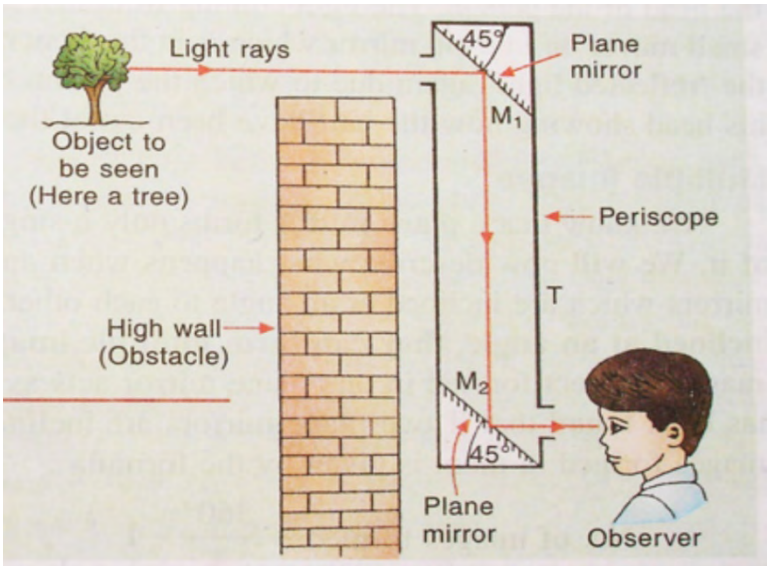


Figure 5.24: A simple periscope.

SNELL'S LAW AND ITS APPLICATION

Dear learner, you are welcome to yet another exciting week in the study of light. We hope you enjoyed last week as you had fun learning about the properties of light and its reflection by mirrors, leading to the formation of images. That was quite interesting.

However, you also learnt that one of the properties of light is refraction or bending. Can you imagine how this happens? Just dip a straight stick in water and observe what happens to its 'straightness'. This is what exactly happens to light. Let us now delve into the concept of refraction of light.

Refraction of light

When you dip a straight stick into water, what do you observe of it? It appears bent just as it enters the water, isn't it? This is what exactly happens to light as it passes from one medium into another.

When a ray of light travels from one medium (like air) into another medium of a different optical density (like water or glass), its speed changes. This change in speed causes the light ray to bend at the boundary between the two media. This bending is called refraction.

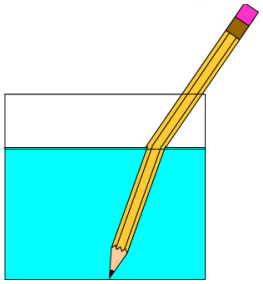


Figure 5.25: Demonstrating refraction of light.

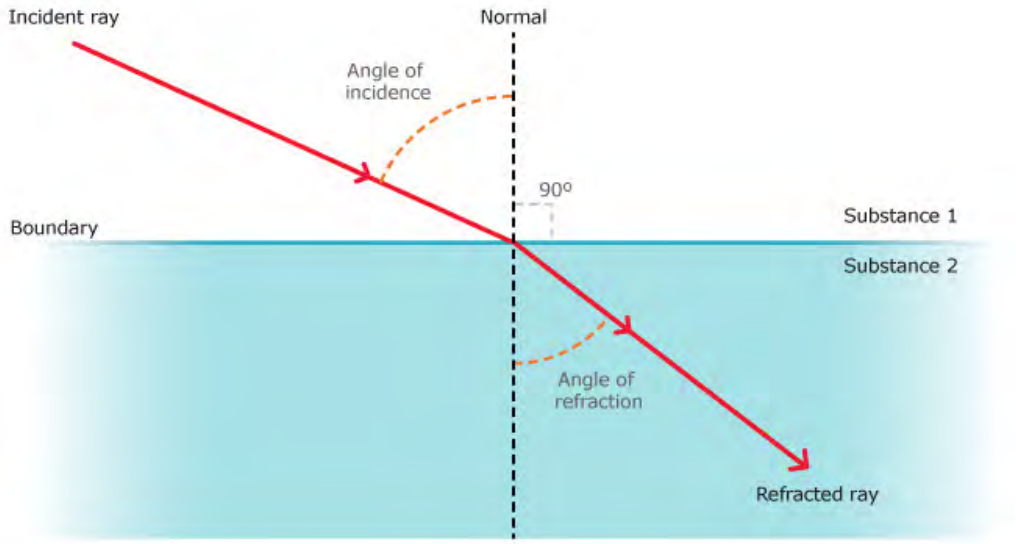


Figure 5.26: Ray diagram of refraction of light.

Definition of Related Terms

1. **Incident ray:** The incoming ray of light.
2. **Refracted ray:** The transmitted ray of light into another medium.
3. **Medium of incidence:** The medium in which light travels before it strikes the boundary.
4. **Medium of refraction:** The medium through which refracted ray travels.
5. **Point of incidence:** The intersection of the incident ray and the boundary.
6. **Normal:** An imaginary line drawn perpendicular to the boundary at the point of incidence.

7. **Angle of incidence (*i*):** The angle between the normal and the incident ray.
8. **Angle of refraction (r):** The angle between the normal and the refracted ray.

In order to understand the concept of refraction of light better, we need to perform an activity.

Now, in groups of 3-5 people, perform ***Activity 5.3*** to verify refraction of light.

Activity 5.3 Refraction of light

Aim: To show the refraction of light between air and water.

What you need

- Glass of water
- Pencil/straw

What to do

a. Fill the glass about two-thirds full with water.

b. Place the pencil or straw into the glass of water so that it is partially submerged.

c. Look at the pencil from the side, at the point where it enters the water.

Observation

a. How does the pencil appear at the air-water boundary?

b. Why does this happen?

c. Discuss your observation with your elbow friends.

Conclusion

What conclusion can you draw from the activity?

Write it down in your jotter.

Precaution(s) taken for accuracy: What did you do to achieve the objective of the activity? Give two examples.

REFRACTIVE INDEX

The refractive index of a medium is a measure of how much the speed of light is reduced when it passes through that medium.

A higher refractive index means that light slows down more when travelling through the material compared to another medium.

It's defined as the ratio of the speed of light in a vacuum (c) to the speed of light in the medium (v).

Thus, $n = \frac{c}{v}$,

Where n = refractive index of the medium,

c = speed of light in vacuum and

v = speed of light in the medium.

Table 5.3: Refractive Indices of Some Media

Material	Index of Refraction
Air	Very close to 1 (around 1.00029)
Water (room temperature)	1.33
Ethyl Alcohol	1.36
Glass	1.50
Diamond	2.417
Vacuum	1

Effects of refractive index

The higher the refractive index of a material is, the more light rays will bend and slow down as they enter that material. From ***Table 5.3*** above, light rays will bend and slow down the most in diamond, while they bend and slow down the least in air. This significant bending of light by diamond creates intense internal reflections, which enhance its sparkling appearance.

Snell's Law

This describes how light bends (refracts) when it passes from one medium to another, like from air into water or glass.

It states that the ratio of the sine of the angle of incidence to the sine of the angle of refraction is equal to the ratio of the refractive indices of the two media.

Snell's law formula

$$n_1 \sin\ominus_1 = n_2 \sin\ominus_2$$

What the symbols mean

1. **n_1 (Refractive Index of the first medium)**
   a. This tells us how much the medium slows down light compared to its speed in a vacuum.

b. Air has a refractive index close to 1.00 (because light barely slows down).
c. Water has a refractive index of about 1.33 (light slows down more).
d. Glass can have an index ranging from 1.5 to 1.9, depending on the type.

2. **θ_1 (Angle of Incidence)**
   a. This is the angle between the incoming light ray and the normal (an imaginary line perpendicular to the surface).
   b. The larger the angle, the more dramatic the potential bending.

3. **n_2 (Refractive Index of the second medium)**
   a. If light enters a denser medium (higher refractive index) from a less dense medium, it slows down and bends towards the normal.
   b. If light enters a less dense medium (lower refractive index) from a denser medium, it speeds up and bends away from the normal.

4. **θ_2 (Angle of refraction)**
   a. This is the angle between the refracted light ray and the normal inside the second medium.
   b. It depends on the ratio of the refractive indices and the incident angle.

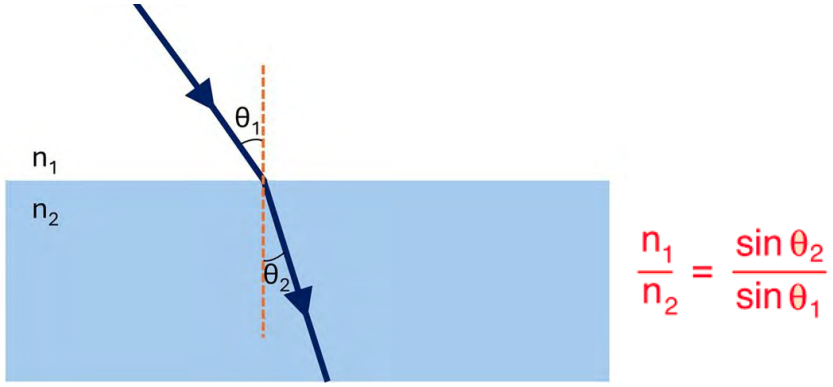


Figure 5.27: Snell's law

How Snell's law works

1. If light goes from a less dense medium to a denser medium (e.g., air to water), it bends toward the normal (line perpendicular to the surface).
2. If light goes from a denser to a less dense medium (e.g., water to air), it bends away from the normal
3. Snell's Law explains why a pencil/straw looks bent in a glass of water and why lenses focus light in cameras and eyeglasses.

Worked examples

5.4. If the speed of light in a medium is 2.25×10^8m/s, what is the refractive index of the medium? (Speed of light in vacuum c=3.00×10^8m/s). **The solution can be found in Annex 5.0.**

5.5. If the refractive index of a medium is 2.0, what is the speed of light in the medium? (Speed of light in vacuum $c=3.00\times10^8$m/s)

Solution to 5.5

The speed of light in a medium is calculated using, $n = \frac{c}{n}$

where:

a. v = speed of light in the medium

b. c = speed of light in vacuum (3.00×10^8 m/s)

c. n = refractive index of the medium (2.0)

Substituting the values, $v = \frac{3.00 \times 10^8}{2.0}$, $v = 1.50 \times 10^8$ m/s

5.6. Light travels from air (refractive index = 1.00) into glass (refractive index = 1.50) at an angle of incidence of 30°. Find the angle of refraction. **The solution can be found in 5.0.**

5.7. Light passes from air ($n_1=1.00$) into an unknown medium. The angle of incidence is $\theta_1=60^\circ$, and the angle of refraction is $\theta_2=30^\circ$.

Find the refractive index n_2 of the medium.

Solution to 5.7

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

$1.00 \times sin60° = n_2 \times sin30°$

$0.8660 = n_2 \times 0.6$

$n_2 = \frac{0.8660}{0.5}$

$n_2 = 1.732$

Applications of Snell's law

1. **Design of lenses**

   Snell's Law is crucial in designing optical lenses used in cameras, microscopes, and eyeglasses. By understanding how light refracts through different materials, manufacturers can create lenses that precisely focus light to improve image quality or correct vision.

2. **Fiber optic communication**

   In fibre optics, Snell's Law helps engineers design the core and cladding of optical fibre to achieve total internal reflection. This principle ensures that light signals travel long distances with minimal loss, which is essential for high-speed internet and telecommunications.

3. **Optical Instruments**

   Snell's Law is used in the development of various optical instruments like telescopes, binoculars, and periscopes. It helps in calculating the necessary angles and materials for prisms and mirrors to correctly direct light and produce clear images.

4. **Underwater Imaging**

   Snell's Law explains how light bends when entering water from air, which is critical for designing underwater cameras and instruments. Understanding refraction helps correct distortions in underwater photography and videography.

5. **Gemology/Study of gemstones**

   In gemology, Snell's law assists in cutting precious stones at angles that enhance their inherent brilliance. Proper cutting techniques that consider light refraction increase the sparkle and value of gemstones. It helps to determine real gemstones from fake ones

6. **Meteorology**

   Snell's law helps meteorologists understand phenomena like mirages, where variations in the refractive index of air due to temperature gradients cause the bending of light rays from distant objects, creating optical illusions.

7. **Medical imaging**

   Some medical imaging techniques, such as optical coherence tomography, rely on understanding how light refracts through different tissues. Snell's Law assists in interpreting the data to provide accurate images.

Real and Apparent depth

When light passes from one medium to another, such as from water to air, it bends or refracts. This refraction causes objects submerged in water to appear shallower than they are. The difference between the actual depth (real depth) and the perceived depth (apparent depth) is an important concept in optics. Understanding real depth and apparent depth does not only help in physics but also has practical applications in fields such as underwater exploration, photography and fishing.

Real/Actual depth

Real depth is the actual vertical distance between an object submerged in a medium and the surface of that medium. In other words, the distance from the surface to where the object really is in the medium

Real depth is affected by the following factors:

1. **Density of medium:** This does not change the real depth itself but can affect the ease and method of measurement. In denser mediums, specialized instruments may be required to determine buoyancy or resistance.
2. **Position of object:** Real depth is directly determined by the object's distance from the surface of the medium. This is a key factor in measuring any depth and forms the basis for calculating real depth.
3. **Measurement tools:** The accuracy of the type of tool used (such as a ruler, depth gauge, or sonar) influences how precisely the real depth is recorded. Faulty tools or human error can lead to inaccurate depth readings.

4. **Variations of water surface:** Changes in water level due to presence of tides, waves, or environmental factors may temporarily affect the measured depth. These changes must be considered in real-time depth assessments, especially in marine or hydrological studies.

Apparent depth

This is the depth at which an object appears to be when submerged in a transparent medium, such as water or glass. The apparent depth of an object appears shallower than its actual depth due to refraction of light.

Factors which affect apparent depth are as follows:

1. **Refractive Index of the medium:** This determines how much light bends when it passes from one medium to another. A higher refractive index results in a greater difference between the real and apparent depth. For example: Light bends more in glass (higher refractive index) than in water.
2. **Angle of observation**: The apparent depth depends on the angle at which the observer views the object. When viewed normally (perpendicularly), the effect of refraction is minimal. When viewed at an angle other than perpendicularly the bending of light increases, making the object appear even shallower.
3. **Real depth of the object: A** greater real depth increases the difference between the actual and apparent positions. Objects closer to the surface show less noticeable displacement.
4. **Optical properties of the medium:** Different materials such as air, water and glass have different optical densities and refractive indices. The change in perception of depth depends on the difference between the refractive indices of the two media.
5. **Curvature of surface:** If the surface of the medium is curved (like in a lens or rippling water), it causes light to bend differently at different points. This results in non-uniform apparent depth, which is often observed in curved containers or lenses.
6. **Temperature of medium:** Temperature can slightly affect the refractive index of a medium. For example, warm water has a lower refractive index than cold water. This alters apparent depth slightly.

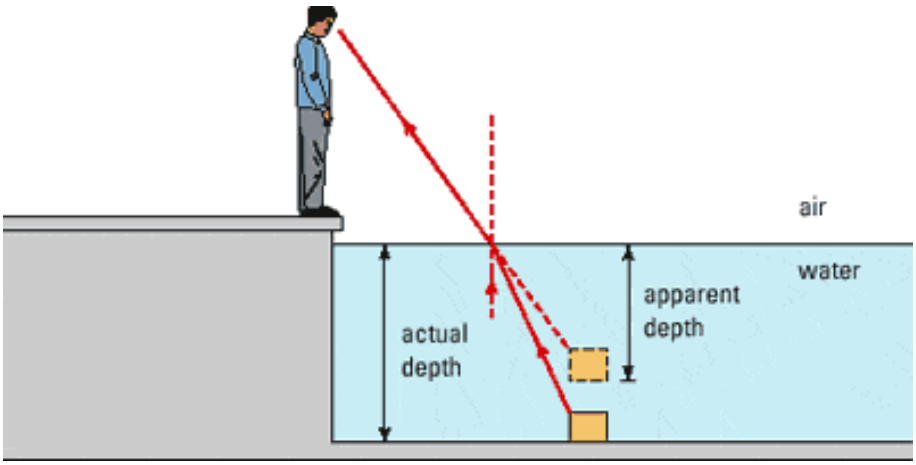


Figure 5.28: Real and apparent depth

Real and Apparent Depth Formula

This can be used to calculate the refractive index of the medium in which an object is viewed. Thus,

$$\text{Refractive index} = \frac{\text{Real depth}}{\text{apparent depth}}$$

Worked examples

5.8. A coin is placed at the bottom of a beaker filled with water. The real depth of the coin is measured to be 12 cm. If the refractive index of water is 1.33, calculate the apparent depth of the coin as observed from directly above the beaker.

Solution

$$\text{Apparent depth} = \frac{\text{Real depth}}{\text{Refractive index}}$$

Given,

Real depth = 12 cm, refractive index of water = 1.33

Substituting values, Apparent depth = $\frac{12\text{ cm}}{1.33}$ = 9.02 cm

5.1.1. An object appears to be at a depth of 10 cm when viewed from directly above a tank filled with water. If the refractive index of water is 1.33, calculate the real depth of the object. **The solution can be found in Annex 5.0.**

Dear learners, let us perform another activity (***Activity 5.4***), which involves the use of real depth and apparent depth to find the refractive index of named liquids. Do this in groups of 3-5 people.

Activity 5.4 Finding the refractive index of liquids

Aim: To use real depth and apparent depth to find the refractive index of some liquids.

What you need

- A transparent container (glass or plastic).
- Water, coconut oil.
- A coin or small object.
- A ruler or measuring tape.
- A piece of cardboard.

What to do

1. Place the coin at the bottom of the container.
2. Fill the container with water to a certain depth.
3. Measure the total depth of the water in the container (from the surface to the coin) – this is the real depth.

4. Observe the coin from above, at an angle (around 45 degrees is suggested). The coin will appear to be raised due to refraction. Use a piece of cardboard to block the view of the coin, then slowly add water until the coin comes back into view. Measure its location from the surface of the water as the apparent depth.
5. Calculate the refractive index (n) of water, using the formula: n = real depth / apparent depth.
6. Repeat the process using coconut oil.
7. Compare your calculated values to theoretical values.

Observations

a. How do your calculated values compare with theoretical values?

b. Share your thoughts with your elbow friends.

Conclusion

a. What conclusion can you draw from the activity?

b. Write it down for a class discussion.

TOTAL INTERNAL REFLECTION (TIR)

Now, imagine you are walking alone down a tarred road on a hot sunny day. Suddenly, you notice something ahead; it looks like a pool of water on the road, with people seemingly walking through it. You keep walking, expecting to reach it… but strangely, no matter how far you go, it never gets closer. Why? This is not real water at all; it is a mirage, an optical illusion created by the phenomenon of total internal reflection. Let's explore how this fascinating effect happens.



Figure 5.29: Mirage, an optical illusion

Total Internal Reflection (TIR)

This is an optical phenomenon that occurs when light traveling from a medium with a higher refractive index (optically denser), such as water, to a medium with a lower refractive index (optically less dense), such as air, strikes the interface between the two media at an angle of incidence greater than a specific angle called the critical angle. (Critical angle is the

specific angle of incidence at which light travels from a denser to a less dense medium that results in an angle of refraction of exactly 90°).

In the process, the incident light is completely reflected back into the denser medium on hitting the boundary of the two media. For total internal reflection to take place, some conditions must be satisfied. These are stated below.

Conditions necessary for TIR

1. The light must travel from an optically denser medium towards an optically less dense medium. Eg: From water to air, glass to water.
2. The angle of incidence must be greater than a certain critical angle, c, i.e. i > c.

Under these conditions, instead of the incident light refracting into the less dense medium, all of it is reflected back into the denser medium.

How Total Internal Reflection occurs

1. As light moves from a denser to a less dense medium, it speeds up and bends away from the normal. For angles less than the critical angle, the incident light ray undergoes refraction and a weak internal reflection. As the angle of incidence increases, the angle of refraction gets closer to 90 degrees.
2. At the critical angle, the incident light ray is refracted at 90° along the boundary of the two media. It is described as grazing the boundary and is referred to as a grazing ray.
3. If the angle of incidence is increased further, there's no angle of refraction greater than 90° possible according to Snell's Law. Instead, the energy of the light wave is entirely reflected back into the original medium (without any refraction).

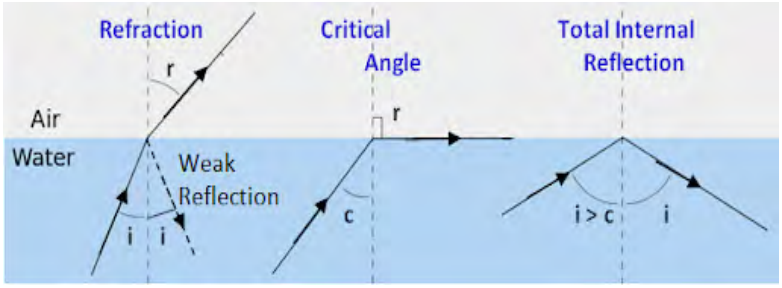


Figure 5.30: Total internal reflection

- **Key question:** How do organisms living below water receive light for their life activities?



Figure 5.31: Light under water by TIR

Applications of Total Internal Reflection

TIR is a crucial phenomenon with numerous important applications as follows:

1. **Optical Fibres:** This is perhaps the most significant application. Optical fibres are thin strands of glass or plastic that transmit data as pulses of light. The light signals are guided along the fibre by repeated total internal reflection at the interface between the high refractive index core and the lower refractive index cladding. This allows for high-speed, long-distance communication with minimal signal loss.

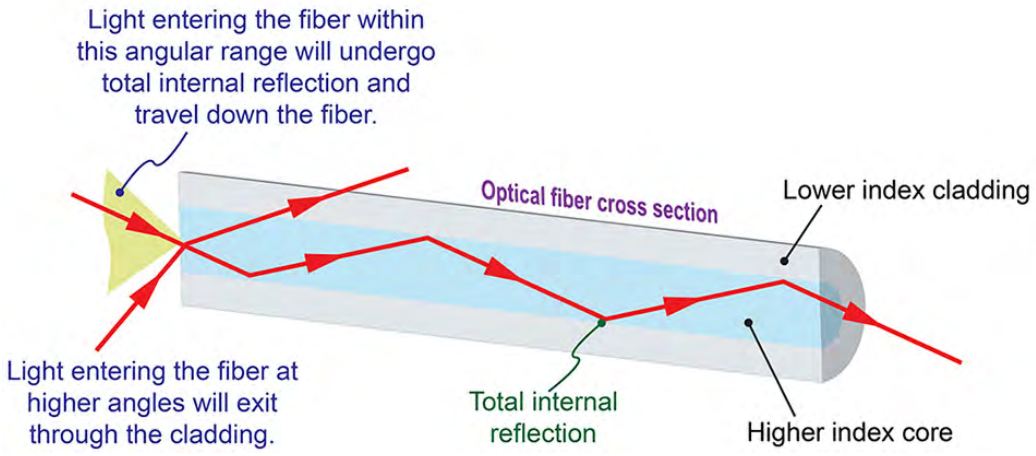


Figure 5.32: Optical fibre

2. **LASER** is an acronym for Light Amplification by Stimulated Emission of Radiation. LASERS produce a narrow, focused beam of light, unlike regular light sources such as bulbs. This focused beam is used in a variety of technologies and instruments and is often used as the light source in fibre optics.



Figure 5.33: LASER beams.

3. **Prisms in optical instruments:** Prisms are used in binoculars, telescopes, and single-lens reflex (SLR) cameras to reflect light and change its path. Using TIR within a prism provides a highly efficient reflection with minimal light loss, often superior to using mirrors.
4. **Medical endoscopes**: Endoscopes use bundles of optical fibres to transmit images from inside the human body to a viewing screen. Light is shone into the body through

some fibres, and the reflected light carrying the image is transmitted back through other fibres, all relying on TIR.

5. **Sensors**: TIR-based sensors can be used to measure various physical quantities or detect the presence of specific substances by detecting changes in the conditions required for TIR at an interface.
6. **Gemstones**: The brilliance and sparkle of gemstones like diamonds are partly due to their high refractive index and the occurrence of total internal reflection within the cut facets, trapping and reflecting light back to the observer.
7. **Mirages**: This is an optical illusion. Mirages are a natural example of TIR occurring in the atmosphere. Light travelling down from higher atmosphere passes from cold to warm to hot air (from denser to less dense medium) near the ground. In so doing, it bends gradually away from the ground (away from the normal) until it re-enters the atmosphere. This creates a virtual image of the blue sky on the ground, viewed as a pool of water by an observer. It is normally viewed on a hot road (usually tarred ones) or desert.

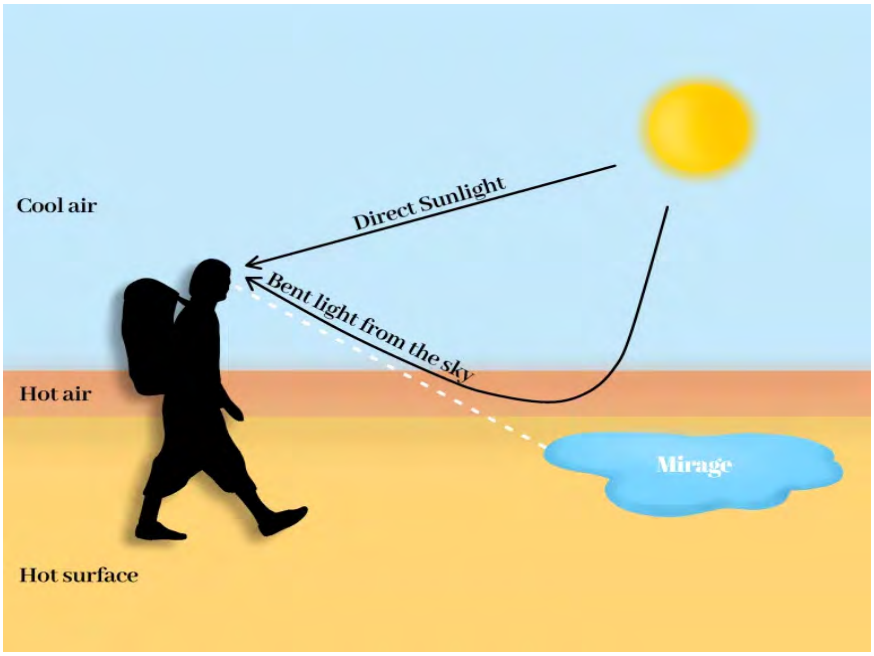


Figure 5.34: Formation of mirage

Learners, we learnt earlier that one of the uses of total internal reflection is the use of optical fibres to carry information

Let us perform the following activity to demonstrate how that basically happens.

Perform ***Activity 5.5*** in small groups of 3-5 people.

Activity 5.5 Demonstration of fibre optics

Aim: To show how light carries information through a fibre using total internal reflection.

What you need

- A large transparent plastic bottle.
- Water.
- Laser pointer or flashlight.
- Tape or cork with a small hole.

What to do

1. Fill the bottle with water and make a small hole on its side near the bottom.
2. Shine the laser through the back of the bottle and straight out of the hole you have made while water flows out of the hole.

Observation

a. Carefully examines how the light bends and follows the stream of water.

b. Why do you think this happens? Discuss your observation with your elbow friends.

Conclusion: What conclusion can you draw from the activity?

Safety measures: What safety measures must you adopt when using a LASER beam? Why must you adopt such measures? Write your responses down.

Activity 5.6 Produce a Poster Demonstrating the Applications of Lenses in Optics

1. Create a single-sided A4 poster highlighting some of the applications of lenses in various fields.
2. Use pictures and diagrams to make your poster eye-catching.
3. Try to include a summary of how mirrors are used in each context.

Some ideas for fields of optics are:

a. Spectacles

b. Telescopes

c. Fibre-optics

Activity 5.7 The Role of Lenses in Manipulating Light

Write a single paragraph response to the question 'How are lenses used to manipulate light and where do we encounter examples of this on a day-to-day basis?'

Activity 5.8 Concept Map

Produce a concept map discussing some of the concepts of light energy that we have made so far, including

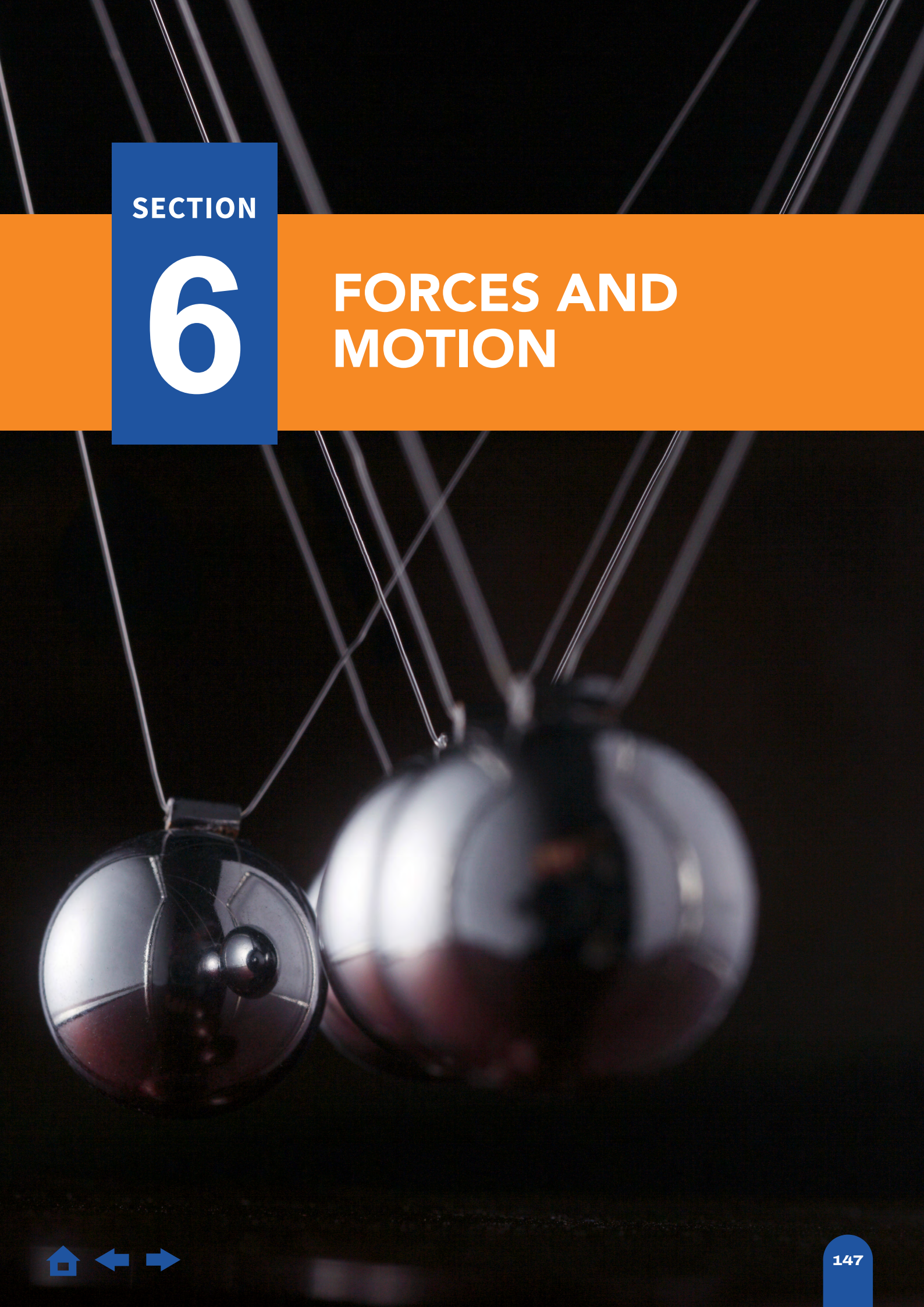
a. Reflection
b. Types of mirrors and their effect on light
c. Refraction
d. Snell's Law
e. Applications of refraction
f. Total Internal Reflection
g. Applications of TIR

EXTENDED READING

Click (How to make a periscope) **Video:** https://youtu.be/B5NCqIBM34o

REVIEW QUESTIONS

1. Explain how light allows us to see things and discuss how different sources of light are used in places like homes, schools, and hospitals. Give real-life examples to support your answer.
2. Light travels at a speed of 3×10^8 m/s. If the distance between the Sun and Earth is 1.5×10^{11} metres;
   a. Calculate how long it takes sunlight to reach Earth in minutes.
   b. Evaluate the importance of this natural light in human activities.
3. Explain why a straw appears bent when placed in a glass of water, using the concept of refraction.
4. In a group of 5 members, design and construct a functional optical device (such as a periscope, magnifier, projector, or simple microscope, pin) using locally available materials. Demonstrate how your model works and explain the scientific principles of reflection or refraction used. Justify how this device could solve a problem in your community or daily life.



SECTION

6 FORCES AND MOTION

VIGOUR BEHIND LIFE

Understanding forces and their everyday roles

INTRODUCTION

In our daily lives, we are always surrounded by forces that affect how things move and behave. Gravity pulls us toward the Earth, friction slows down moving objects, and magnets attract certain metals. Even when we push, pull, or lift something, we are applying a force. These forces are at work all around us, often without us noticing.

When objects collide, they can behave in different ways. Sometimes they bounce apart with no loss in energy; this is called an elastic collision. Other times, they stick together or change shape; this is an inelastic collision. By learning about these types of forces and collisions, we can better understand everyday situations, from how cars move and stop, to how balls bounce in sports.

KEY IDEAS

- Conservation of linear momentum.
- Types of collisions and their effects.
- Types of force and their applications.
- What force is.

FORCES

A force is a push or a pull which acts on an object. This interaction can cause the object to start moving, stop moving, speed up, slow down, change direction or change its shape. The results of this interaction are known as effects of force. Force is a vector quantity, meaning it has both magnitude (how much force) and direction.

Unit of force

The standard unit of force, by the convention of International System of Units (SI), is the newton (N). One Newton is defined as the force required to accelerate a one-kilogram mass at a rate of one metre per second squared ($1\ N = 1\ kg{\cdot}m/s^2$).

Types of Forces

Forces can be broadly put into two main categories. These are

1. Contact forces,
2. Non-contact/field forces (or forces at a distance).

Contact Forces

Contact forces are types of force that result when the source of the force is in a physical touch with the body to which the force applies. Examples of contact forces:

1. **Muscular force (Applied force):** This is the force applied by the action of muscles in living beings (humans or animals). It is the force we use for everyday activities like lifting, pushing, pulling, walking, and internal bodily functions like breathing and digestion. Its daily applications include:
    a. Pushing a door,
    b. Pulling a cart,
    c. Lifting a bag,
    d. Chewing food,
    e. An animal ploughing a field.
2. **Normal force**: It is defined as the support force by a surface on an object in contact with it, acting perpendicular to the surface. When an object rests on a surface, the surface exerts a push, upward, on the object such that the push is perpendicular to the surface. This supporting upward push is called normal force. Instances of normal force include:
    a. A book resting on a table (supported by the normal force from the table).
    b. A person standing on the ground (supported by the normal force from the ground).
3. **Tension force:** This is the force transmitted through a string, rope, cable, or wire when it is pulled tight by forces acting from opposite ends. The tension force is directed along the length of the string and pulls equally on the object on its opposite ends. Its daily applications include:
    a. pulling a bucket of water from a well using a rope.
    b. pulling in a tug-of-war
    c. plucking stretched guitar strings.
4. **Spring force:** It is the restoring force exerted by a spring to return to the natural length when stretched or compressed, acting in the opposite direction of the displacement. This is the force applied by a compressed or stretched spring to any object that is attached to it. The force acts to restore the spring to its original (equilibrium) shape. Some of its daily applications include:
    a. Pens with click mechanisms use springs to extend and retract the pen tip.
    b. Door closers have springs that automatically pull doors shut after opening.

c. Spring mattresses and cushions contain coils that compress and return to shape for comfort and support.

d. Trampolines use springs to provide the bouncing action when someone jumps on them.

e. Mechanical clocks and watches rely on wound springs to store and release energy gradually.

f. Suspension systems in vehicles include springs to absorb shocks and maintain stability.

g. Wound-up toys use internal springs to store energy and create motion when released.

h. Clothespins (clothes pegs) and paper clips include springs to maintain a firm grip on objects.

i. Spring-based weighing scales measure weight based on how much the spring stretches.

j. Safety pins use springs to enable secure opening and closing mechanisms.

5. **Upthrust**: Upthrust is also known as buoyant force, is a vertical upward force that a fluid (a liquid or gas) applies to an object placed in it. Its daily applications can be seen in the following activities:

a. When you swim, you feel lighter in water. That is because upthrust pushes your body upward, helping you to float.

b. Boats and ships float on water because the upthrust balances their weight. Their shape helps them displace enough water to stay afloat.

c. Plastic or wooden fishing floats stay on the surface of water due to upthrust. When a fish pulls on the line, the float may dip, showing a change in balance.

d. Submarines control upthrust by filling or emptying tanks with water or air. This helps them sink or float as needed.

e. A hot air balloon rises up the atmosphere because heated air inside it is lighter, creating greater upthrust from the air outside it than the balloon's weight.

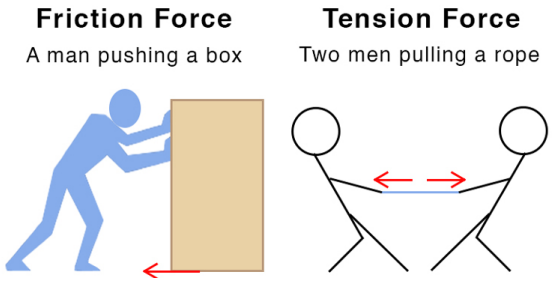


Figure 6.1: Contact forces

Non-contact/Field forces (Forces at a distance)

These are forces which act on objects which are not in physical touch with the source of the force. Examples of non-contact forces

a. **Gravitational Force:** This is the force of attraction between any two objects, in space, with mass. The more massive the objects and the closer they are, the stronger the gravitational force between them is. On Earth, gravitational force is experienced as force of gravity which pulls everything towards the centre or core of Earth. Daily applications of gravitational force are as follows:

i. Keeps us and objects on the ground.

ii. Responsible for the orbits of planets around the sun and the Moon around Earth.

iii. One of the best examples of gravitational force is a falling object. When you drop a book, it falls to the ground due to the gravitational force pulling it downward.

iv. The gravitational pull of the Moon and the sun on Earth's oceans causes the rise and fall of the level of the sea. This is known as tidal movement.

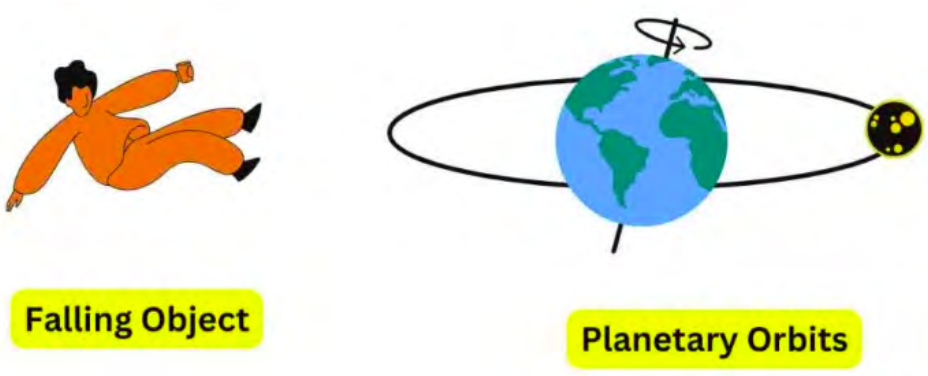


Figure 6.2: Gravitational force

b. **Magnetic Force:** This force is applied by magnets to magnetic materials like iron, nickel, cobalt or other magnets. It can be attractive (pulling together) or repulsive (pushing apart). Magnets have two poles, North and South. Two South poles or two North poles (Like poles) near each other repel, while a North pole and a South pole (Unlike poles) near each other attract. This creates the law of magnetism which states, "like poles repel, unlike poles attract.

Daily uses of magnetic force include the following

i. Magnets help keep refrigerator and freezer doors tightly closed. A magnetic strip inside the rubber seal ensures the door stays shut, preserving cool air and saving energy.

ii. Magnets are used in the speakers, microphones, and vibration motors of smartphones and laptops. Some laptop lids also use magnets to trigger sleep mode when closed.

iii. Electromagnets are used in traditional mechanical doorbells. When pressed, the circuit activates an electromagnet that pulls a metal striker to hit a bell.

iv. Magnets are used in MRI (Magnetic Resonance Imaging) machines, which produce detailed internal body images without using X-rays.

v. Motors in electric fans and washing machines use electromagnets to convert electricity into motion.

c. **Electrostatic Force:** This force exists between electrically charged objects or particles. Like charges repel each other, while opposite charges attract. This force arises from the accumulation of electric charges on the surface of an object, often due to friction.

Daily applications of electrostatic force can be seen in the following situations

i. Clothes cling together due to static electricity after drying.
ii. Spray painting uses electrostatic forces for even coating.
iii. Lightning occurs due to charge buildup in clouds.
iv. Hair stands up when rubbed with certain materials due to static buildup.
v. Plastic wrap sticks to surfaces using electrostatic adhesion.
vi. Charged balloons attract small paper pieces.
vii. Electrostatic charges help in inkjet printing.

Frictional Force

Friction is a contact force that opposes the relative motion or the tendency of such motion between two surfaces in contact. It acts parallel to the surfaces.

Types of Friction

1. **Static friction:** The friction that acts on objects when they are stationary and prevents them from starting to move. For example, the force that keeps a heavy box from moving when you first start to push it.
2. **Kinetic friction (Dynamic friction):** The friction that acts on objects when they are moving. Its magnitude is less than that of static friction. It takes the following forms:

   a. **Sliding Friction**: Occurs when one solid surface slides over another. E.g., pushing a book across a table.

   b. **Rolling Friction:** Occurs when an object rolls over a surface. E.g., a ball rolling, wheels of a car. Rolling friction is generally much less than sliding friction, which is why wheels are so useful.

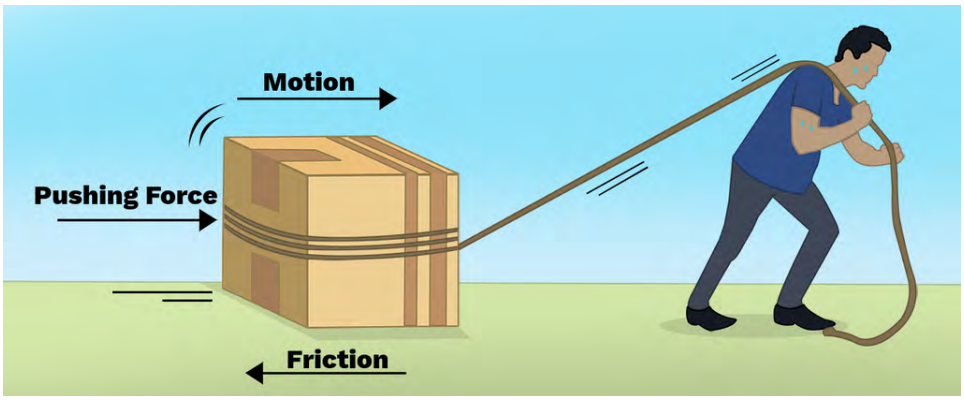


Figure 6.3: Sliding friction

Some Good Effects/Advantages of Friction

1. **Walking/Running:** Friction between our shoes and the ground allows us to push off and move forward without slipping.
2. **Gripping:** Friction allows us to hold objects.
3. **Writing:** Friction between a pen/pencil and paper allows the ink/graphite to transfer.
4. **Braking:** Brakes in vehicles use friction to slow down or stop.
5. **Lighting a matchstick:** Friction generates heat to ignite the match.
6. **Holding nails and screws:** Friction keeps them in place in wood or walls.
7. **Sharpening tools:** Friction reduces the area of the cutting edge or piercing tip of tools.
8. **Grinding/milling:** Friction causes grains of cereals, food materials and other substances to be ground or milled.

Bad effects /disadvantages of friction

1. **Wear and tear:** Friction causes rubbing surfaces to wear out overtime E.g., soles of shoes, machine parts and tires.
2. **Energy loss:** Friction converts useful kinetic energy into heat, reducing the efficiency of machines. For example, parts of machines and engines get hot due to friction.
3. **Slows movement:** We need to apply more force to overcome friction when moving on a rough surface. E.g., an untarred road or the one tarred with raw chippings.
4. **Bruises:** Friction causes bruises to be sustained during falls.
5. **Fire:** Overheating caused by friction in machines and engines may result in fires.

Key question

1. Write down your answer in your notebook.
2. In what ways do you think friction can be reduced?

Factors Affecting Friction

Two main factors influence the amount of friction between solid surfaces. These are:

1. **Nature of the surfaces in contact:** Rougher surfaces generally have more friction than smoother surfaces. This is due to the interlocking of irregularities on the surfaces.
2. **Normal force (how hard surfaces are pressed together):** The greater the force pressing the two surfaces together (the normal force), the greater the friction. This is why it's harder to push a heavy box than a light one across the same surface.

Fluid friction/ Drag

Fluid friction, also known as drag, is the force that opposes the motion of an object through a fluid (a liquid or gas).

Factors influencing fluid friction

1. **Viscosity of the fluid:** Viscosity is a measure of a fluid's resistance to flow. Thicker, more viscous fluids (like honey) cause more friction than thinner fluids (like water or air).
2. **Shape of the object:** Objects with a streamlined shape (pointed at both ends and broader in the middle, like fish or an airplane) experience less fluid friction.
3. **Speed of the object:** Fluid friction increases with the speed of the object moving through the fluid. The faster an object moves through a fluid, the greater the drag.
4. **Surface area of the object:** A larger surface area exposed to the fluid generally leads to greater fluid friction.
5. **Nature of the fluid:** Denser fluids generally exert more drag.
6. **Temperature of the fluid:** For gases, fluid friction generally increases with temperature. For liquids, viscosity (and thus fluid friction) often decreases with increasing temperature.

Ways of Reducing Friction

In many situations, reducing friction is desirable to improve efficiency by reducing its bad effects. Some of the ways to reduce friction are as follows:

1. **Lubrication:** Applying lubricants like oil, grease, or graphite between moving parts creates a thin film that separates the surfaces, reducing direct contact and friction. This is common in engine parts, bicycle and motorbike chains.
2. **Streamlining:** Designing objects with smooth, tapered shapes (streamlined shapes) allows fluids (air or water) to flow past them more easily, reducing drag. Examples include the bodies of airplanes, racing cars, ships, birds and fish.
3. **Using rollers/Ball bearings:** Replacing sliding friction with rolling friction significantly reduces frictional force. Ball bearings are used in rotating machine parts such as wheels and motors.
4. **Polishing or powdering surfaces:** Making surfaces smoother reduces the irregularities that interlock, thereby decreasing friction.
5. **Using appropriate materials:** Some materials have naturally lower coefficients of friction (e.g., PTFE, also known as Teflon).
6. **Reducing contact area (in some specific cases of fluid friction):** While for solid friction, area of contact has little direct effect (it is more about normal force and surface nature), for fluid friction, minimising the frontal area can reduce drag.



Figure 6.4: A streamlined body of shark

Increasing Friction

Sometimes, friction is essential and needs to be increased for safety or functionality. Some of the ways by which this can be done are as follows:

1. **Treads on tires and shoes:** The grooves (treads) on tires and shoe soles increase friction, providing better grip on the road or ground, especially on smooth and slippery ones.
2. **Brake pads:** Brake pads in vehicles are made of materials that create high friction when pressed against the brake discs or drums, allowing the vehicle to slow down or stop effectively.
3. **Using rougher surfaces:** For example, gymnasts apply coarse powder to their hands for a better grip. Kabaddi players might rub their hands with soil.
4. **Increasing the normal force:** Pressing surfaces together more firmly increases friction during grinding or milling.
5. **Stopping relative motion:** Static friction is generally higher than kinetic friction. Rougher surfaces are put together to keep things in place.

Daily applications of forces

a. **Think about it**

   i. Why does a ball, thrown upwards, always come down?

   ii. How can you pick up small pieces of paper with a comb after running it through your hair?

   iii. Why is it easier to skate on ice than on a rough road?

   iv. How do boats float?

b. **Try this**

   i. Push a toy car on a smooth floor and then on a carpet. What do you observe about its motion?

   ii. Drop a feather and a small stone simultaneously. Which one reaches the ground first? Why?

   iii. Bring two magnets close to each other in different orientations. What happens?

   iv. Rub a balloon on your sweater and try to stick it to a wall or bring it near small pieces of paper.

c. **Understanding the "why"**

   i. Pushing/Pulling: When you push a door (muscular force), you are applying a force to move it. When you pull a drawer open (muscular force), you are applying a force to change its position.

   ii. Resisting motion (Friction): The toy car stops sooner on the carpet because the frictional force between the carpet and the wheels is greater than between the smooth floor and the wheels. Friction always opposes motion.

iii. Lifting (Upthrust/Buoyancy): When an object is immersed in a fluid (like water or air), it experiences an upward force called upthrust or buoyant force. If the upthrust is equal to or greater than the object's weight, the object floats. This is why ships made of heavy steel can float; their shape displaces a large volume of water, creating a large upthrust. Animals like fish use upthrust to control their depth in water.

iv. Magnetism in daily life: Refrigerator magnets stick due to magnetic force. A compass needle aligns with Earth's magnetic field to show direction.

The concept map of forces illustrated below will give you insight into types of force, their examples and applications. Study it carefully to address the key questions above.

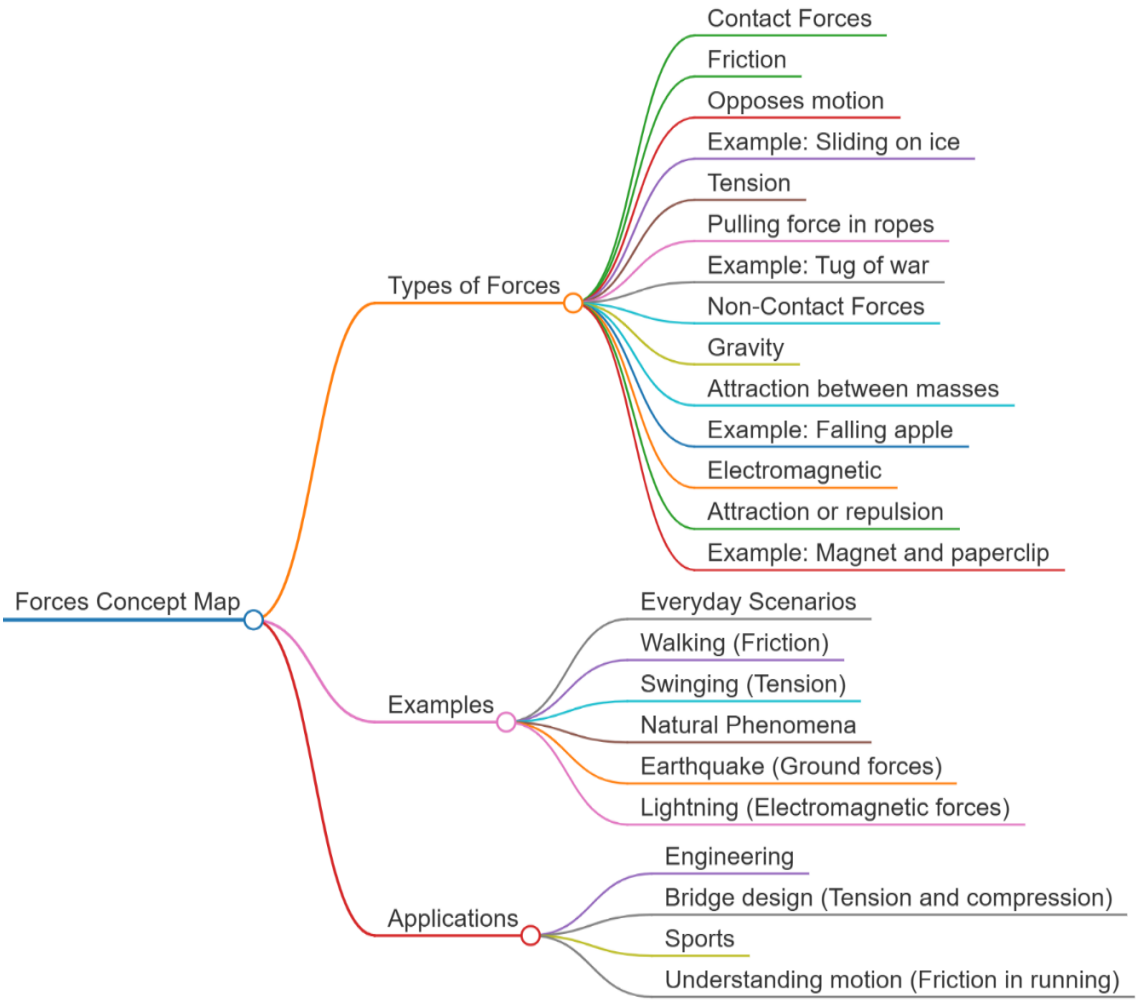


Figure 6.5: Concept map of forces

Upthrust

Upthrust determines whether an object will float or sink in a fluid. To understand this concept, we need to perform the following activity hands-on. Do this in your mixed ability groups.

Activity 6.2 Investigating effects of upthrust on objects

Aim: To observe and explain how upthrust determines whether an object will float or sink in a fluid.

What you need

- A clear container or bucket with water
- Small plastic bottle with cap
- Stone or metal spoon
- Wooden block
- Rubber ball
- Small spring balance (optional)
- String

What to do

1. Look at each object and predict whether it will float or sink. Write your predictions down.
2. Drop each object into the container of water one at a time.
3. Observe which objects sink, which float, and which stay in between.
4. Discuss the results as a group.
5. Hold an object in the air, then slowly lower it into the water while holding it.
6. Record your observation.

Key question: Which type of force could be pushing the object up?

Viscosity

Viscosity is the measure of a fluid's resistance to flow. This force affects how easily fluids flow.

Activity 6.3 Investigating viscosity

Aim: To determine the use of various liquids based on their viscosity.

What you need

- A small ramp (e.g., a smooth board or tray tilted with books)
- Timer
- Measuring cup
- Marker
- Liquids to test (e.g., water, cooking oil, shampoo, liquid soap, honey)

- Spoons or small cups for pouring

What to do

1. Mark a start and finish line on the ramp.
2. Pour a spoonful of each liquid at the top of the ramp and start the timer.
3. Time how long it takes each liquid to reach the bottom.
4. Record the time for each liquid.
5. Compare results and rank the liquids from fastest to slowest.

Activity 6.4 Exploring methods of reducing friction

Aim: To explore methods that reduce friction if it is a nuisance.

What you need

- Various small, identical objects. E.g., wooden blocks
- A standard surface, such as a floor or table
- Sandpaper
- A smooth surface such as a polished tile or Formica
- Fine powder
- Straws or rounded pieces of stick
- Lubricating oil
- Ramp

What to do

1. Create a ramp.
2. Slide the various small objects down the ramp
3. Measure how far an object slides off the ramp onto the standard surface.
4. Modify the roughness and smoothness of the surface.
   a. Place a sheet of sandpaper on the sliding surface (increases friction).
   b. Replace the sandpaper with the smooth surface.
   c. Sprinkle some fine powder (like talcum powder) on the surface.
   d. Place a few straws or round pieces of stick under the object to act as rollers.
   e. If safe and appropriate, apply a tiny amount of oil to the surface (demonstrating lubrication, with caution and proper cleanup).
5. Measure how far the object slides with each modification.

Key questions

Discuss your findings under the following captions:

1. Which methods were most effective in reducing friction?

2. How do these methods relate to real-world applications, e.g., oil in engines, ball bearings in wheels, polishing floors, etc?
3. How do you think friction can be reduced most effectively?

Collisions

In physics, a collision is a dynamic event where two or more objects exert forces on each other over a relatively short period. Collisions can be broadly classified into two main categories. These are:

1. Elastic collisions
2. Inelastic collisions

The key difference between them lies in the conservation of kinetic energy.

1. Elastic collisions

An elastic collision is when objects collide and bounce off without loss of energy. These are collisions in which the colliding particles are not permanently deformed, and the total kinetic energy of the system remains constant. This means that the sum of the kinetic energies of the colliding objects before collision is equal to the sum of their kinetic energies after collision. In an ideal elastic collision, there is no loss of kinetic energy to other forms such as heat, sound and energy forms which may cause deformation.

Characteristics of Elastic Collisions

a. **Momentum is conserved:** The total momentum of the system remains the same before and after the collision.
b. **Kinetic energy is conserved**: The total kinetic energy of the system before the collision is equal to the total kinetic energy after the collision.
c. **Objects separate/Reversible:** The colliding bodies bounce off each other and remain as distinct objects.

Real-world examples of elastic collisions

While perfectly elastic collisions are ideal and do not truly occur in our everyday life experiences, some scenarios come very close.

Examples include

1. **Steel ball bearing:** The collision between two steel ball bearings is a classic example that approximates an elastic collision.
2. **Atomic and subatomic particles:** Collisions between atoms and subatomic particles, such as those in a gas, are considered to be almost perfectly elastic.
3. **Newton's cradle:** The interaction between the swinging balls in a Newton's cradle demonstrates the principles of an elastic collision.

Let us perform the following activity to demonstrate the understanding of Newton's cradle.

Activity 6.5 Demonstrating Newton's cradle

Aim: To explore the effect of an elastic collision.

What you need

- Five small metal balls (e.g., marbles, ball bearings, or even round beads)
- Strong string or thread
- A stiff cardboard box, wooden frame, or hanger (as a support)
- Glue or tape
- Ruler and scissors

What to do

1. Make 5 holes in the top of the frame or hanger, evenly spaced.
2. Tie strings around each ball, making sure each hangs at the same height and barely touches the next.
3. Suspend each ball from the frame so they are in a straight line and just touching each other.
4. Pull one of the balls at the end of the row to the side and let it go (as shown in the diagram below).
5. Record your observation(s).

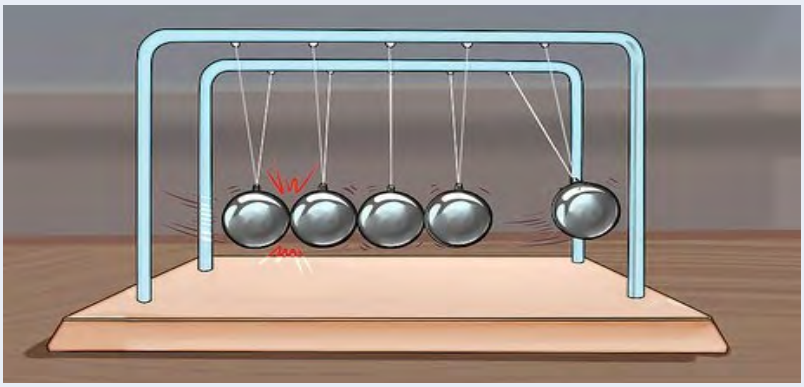


Figure 6.6: A set-up of Newton's cradle

MATHEMATICAL REPRESENTATION

For a one-dimensional elastic collision between two objects with masses m_1 and m_2, and initial velocities u_1 and u_2, their final velocities v_1 and v_2 can be determined using the conservation of momentum and kinetic energy equations as follows:

1. Conservation of momentum

a. $m_1u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$

2. Conservation of Kinetic Energy

a. $\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2\,u_2^2 = \frac{1}{2}m_1\,v_1^2 + \frac{1}{2}m_2\,v_2^2$

Worked examples

6.1. A 5 kg object is moving at a velocity of 3 m/s. What is its momentum?

Solution

Mass = 5kg, v= 3 m/s

p = m × v

= 5 kg × 3 m/s = 15 kgm/s

6.2. Two toy cars, one with a mass of 1.2 kg moving at 2 m/s, and the other with a mass of 1.4 kg at rest, collide elastically. Calculate their total momentum.

a. before collision

b. after collision

Solution is in Annex 6.0.

Inelastic Collisions

In contrast to elastic collisions, an inelastic collision is one where objects collide and the total kinetic energy of the system is not conserved. While momentum is still conserved in an inelastic collision, some of the initial kinetic energy is transformed into other forms of energy, such as thermal energy (heat), sound energy, and the energy needed for a permanent deformation of the colliding objects.

Characteristics of inelastic collisions

1. The total momentum of the system is conserved.
2. The total kinetic energy of the system decreases during the collision.
3. The collision process is not reversible due to the energy lost to other forms.

Types of inelastic collisions

1. Inelastic collision: The objects may or may not stick together after the collision.
2. Perfectly inelastic collision: This is a specific type of inelastic collision where the objects stick together after impact and move with a common final velocity. This results in the maximum possible loss of kinetic energy with no loss in momentum.

Real-world examples of inelastic collision

Most collisions in the world are inelastic. Examples include

1. **Car accidents:** A significant amount of kinetic energy is converted into the crumpling of the car bodies, sound, and heat.
2. **A bullet embedding in a target:** When a bullet is fired into a block of wood and becomes embedded, it's a perfectly inelastic collision.
3. **A ball of clay dropped on the floor:** The clay deforms and does not bounce, indicating loss of kinetic energy.

Mathematical representation: For a perfectly inelastic collision of two bodies with masses m_1 and m_2, initial velocities u_1 and u_2, where the bodies stick together and move with a common final velocity, v;

$$m_1u_1 + m_2u_2 = (m_1 + m_2)\, v$$

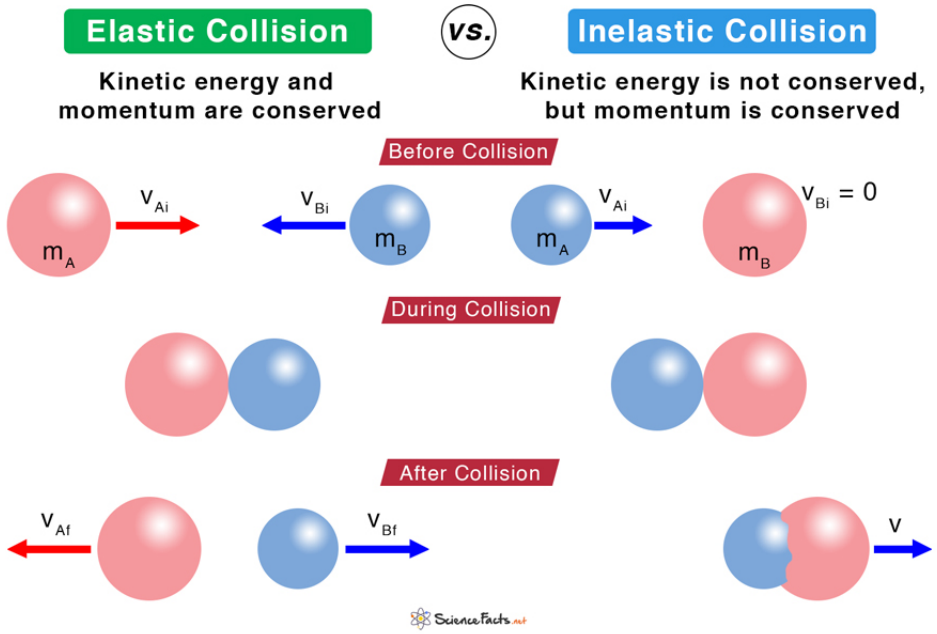


Figure 6.7: Elastic and inelastic collisions compared.

Worked example 6.3

Two cars, Car A with a mass of 1000 kg moving at 20 m/s, and Car B with a mass of 1500 kg moving at 10 m/s in the same direction, collide and stick together. Find their combined velocity after the collision. **Solution is in Annex 6.0.**

Activity 6.6 Modelling and Analysing Collisions

Aim: To investigate whether momentum is conserved in collisions between toy cars.

Hypothesis: The total momentum of the system (cars before collision) will equal the total momentum after collision, within experimental error.

Materials

- Two small toy cars (ideally with similar wheels to reduce friction differences)
- A smooth, level surface or track
- Measuring tape or ruler
- Stopwatch or motion-tracking app/video analysis software
- Mass balance (to measure car masses)

Method

1. Measure the mass of each toy car.
2. Place the cars on a smooth track.
3. Push one car towards the other (initially at rest) to create a collision.
4. Record velocities before and after collision using a stopwatch and distance marks, or by analysing video footage.
5. Repeat for different initial velocities and car mass combinations (e.g., equal masses, unequal masses).

Data Collection

a. Mass of each car

b. Initial velocity of moving car(s)

c. Final velocity of both cars after collision

Data Analysis

a. Calculate initial momentum.

b. Calculate final momentum.

c. Compare before and after values to check for conservation (consider percentage difference).

Conclusion

a. State whether momentum was conserved in the collisions.

b. State whether this collision was elastic or inelastic, and how you know.

c. Discuss experimental errors (e.g., friction, air resistance, timing inaccuracies).

Analysis

Complete the following tasks in your notebook

a. Explain how this experiment using toy cars can be used to predict the outcome of a collision between real cars on the road.

b. List precautions that people can take to avoid collisions. If time is available, turn this into an advisory poster and display it for a gallery walk.

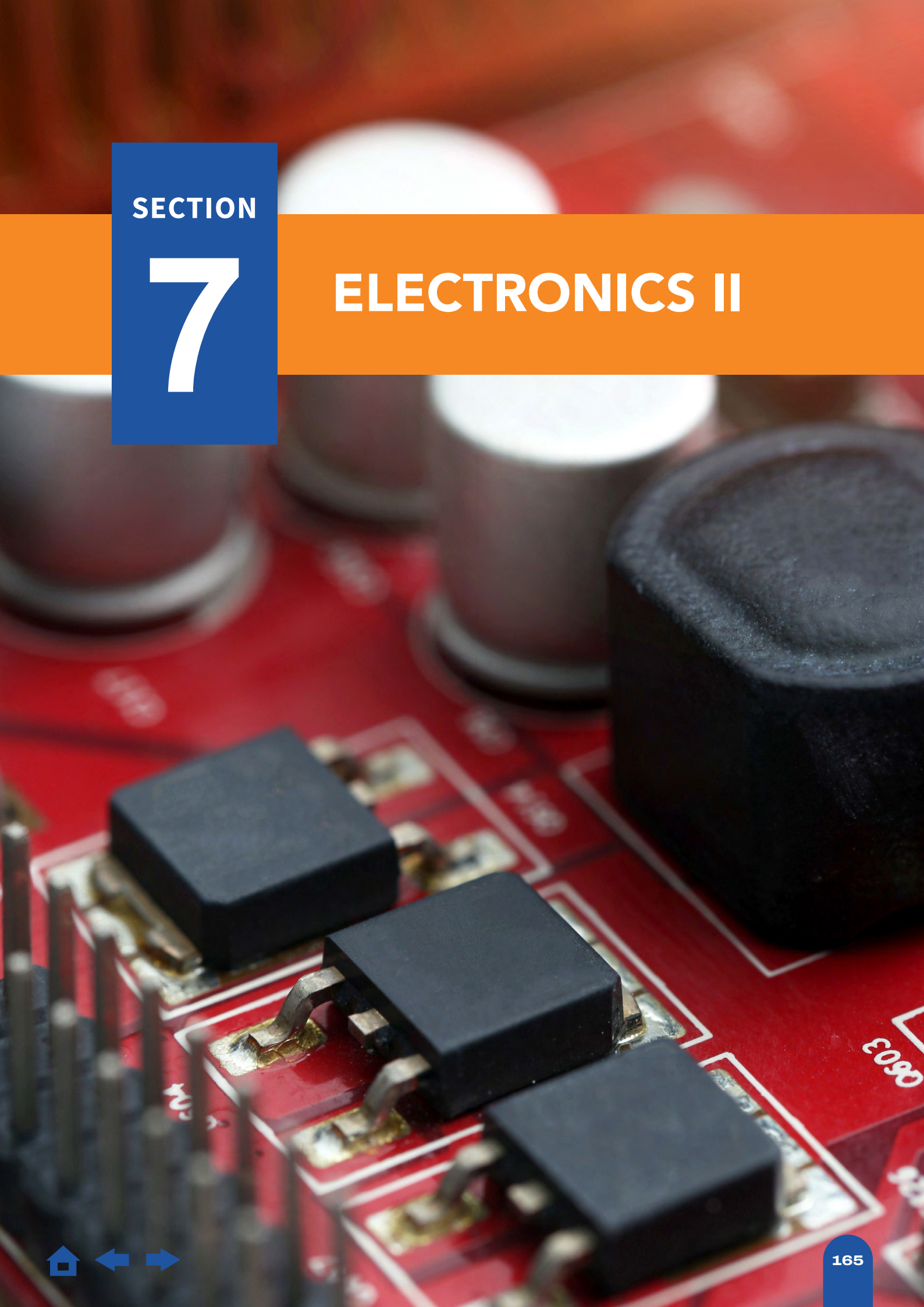
REVIEW QUESTIONS

1. Explain how a car's brakes use friction to stop the car.
2. Compare and contrast elastic and inelastic collisions using real-world examples, and explain what happens to the kinetic energy in each type of collision

SECTION

7

ELECTRONICS II



STRAND: VIGOUR BEHIND LIFE

Consumer electronics and its career opportunity

INTRODUCTION

In this section, you will explore the importance and function of consumer electronic devices commonly used in homes, schools, and workplaces. We cover a range of devices, including mobile phones, televisions, radios, computers, and various kitchen appliances. A key focus is on understanding that these devices are purpose-built to convert electrical energy into useful forms such as sound, light, or motion to perform specific tasks.

KEY IDEAS

- Career opportunities in electronics.
- Components of electronic devices.
- Misconceptions on electronic devices and their correction.

CONSUMER ELECTRONIC DEVICES

Dear learner, in this era of technological advancement, electronic devices are commonplace. We use them at home, places of worship, in school, during public occasions and as personal possessions for various purposes. Let us examine those that are referred to as consumer electronic devices.

These are electrical or electronic gadgets intended for everyday use, primarily in private homes. These devices are an integral part of modern life, assisting with communication, entertainment, and household chores. They range from simple, single-function items to complex, multi-functional smart devices.

Examples of consumer electronic devices:

1. **Mobile Phones:** These are portable devices that allow for communication over a cellular network. Modern smartphones combine the functions of a phone with those of a computer, offering internet access, cameras, and a vast array of applications.
2. **Laptops:** Are portable personal computers that can be easily carried and used in various locations. Being portable and handy, they can be easily placed in the lap, as their name suggests, for comfort of use. Laptops are essential for work, education, and entertainment.

3. **Televisions:** Are devices that receive and display broadcast signals, now commonly used for streaming content from the internet and connecting to other media devices.
4. **Radios:** Are devices that receive electromagnetic waves and convert them into audible sound.
5. **Microwaves:** Are kitchen appliances that uses microwave radiation to heat and cook food quickly.



Figure 7.1: Some consumer electronic devices

Components of Electronic Devices

Every electronic device, regardless of its function, is made up of several key components working together. These components can be broadly categorised as active (requiring a power source to function) or passive (not requiring an external power source). Let's explore the fundamental parts you will find in most consumer electronics.

1. **Power supply unit (Battery or Adapter):** This is the heart of any electronic device, providing the necessary electrical energy for it to operate. This unit functions as follows:
    a. **Battery:** Stores chemical energy and converts it into electrical energy. It is essential for portable devices like mobile phones and laptops.
    b. **Adapter (power brick):** Converts the high-voltage alternating current (AC) from a wall outlet into the low-voltage direct current (DC) that most electronic components require.
2. **Display unit (Screen, LEDs):** This component provides visual output to the user. Its components function as follows:

a. **Screen** (Liquid Crystal Display, LCD; Organic Light Emitting Diode, OLED): Found in devices like phones, laptops, and televisions. It displays complex images and text.

b. **LED** (Light Emitting Diode): Is a simple light used as indicator, for example, to show that a device is on or a battery is charging.

3. **Microcontroller/Processor:** Is often called the "brain" and is the Central Processing Unit (CPU) or microprocessor. This component is the control centre of the device. It executes instructions from the device's software and performs calculations, managing the overall operation of the gadget.

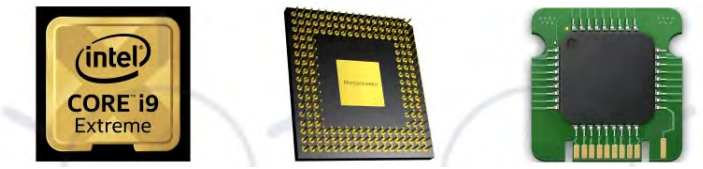


Figure 7.2: Types of microprocessors

4. **Sensor:** This is the input device which detects changes in the environment and converts them into electrical signals that the microcontroller can understand.

   Examples are:

   a. **Touchscreens:** Detect the position of a finger or stylus on the screen.

   b. **Accelerometers**: Detect motion and orientation, used in smartphones for rotating the screen.

   c. **Microphones:** Convert sound waves into electrical signals for recording or communication.

5. **Memory/Storage:** This is for storing information. It consists of:

   a. **RAM (Random Access Memory):** This is the device's short-term memory, used to store data that the processor is actively using. RAM is referred to as the working memory. It is volatile, meaning its contents are lost when the device is turned off.

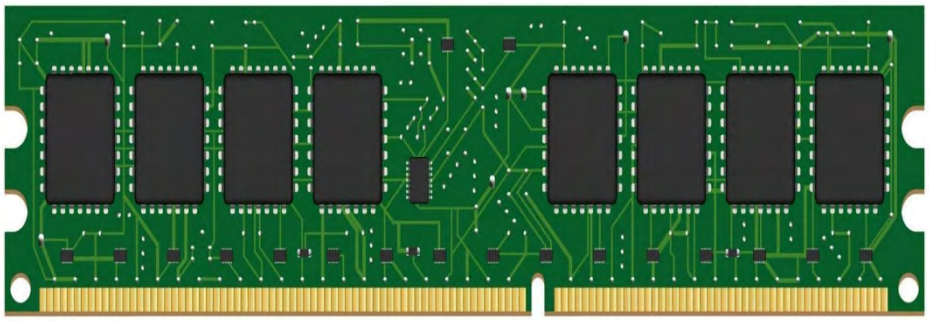


Figure 7.3: Read Access Memory (RAM)

   b. **Hard Disk Drive (HDD) and Solid-State Drive (SSD):** These are the long-term storage devices for the operating system, applications, and user files. They

are non-volatile, retaining data even without power. (They are used to store and retrieve digital information)



Figure 7.4: Hard drives, HDD (left) and SSD (right)

c. **Flash Memory:** A type of non-volatile storage that retains data without power, used in USB drives, memory cards, and smartphones.

6. **Speaker and microphone: Are for audio input and output**

   a. **Speaker:** Converts electrical signals back into sound waves, allowing you to hear audio from your device.

   b. **Microphone (as above):** Captures sound and converts it into electrical signals.

7. **Button, switch, and port:** These provide user interface and connectivity. They allow the user to interact with the device and connect it to other peripherals.

   a. Button and switch: Provide physical controls for functions like power, volume, and navigation. They control electrical circuits by making and breaking contacts.

   b. Port (USB, HDMI, etc.): It is a physical point or slot that allows for data transfer, charging, and connecting to external peripherals.

8. **Printed Circuit Board (PCB):** Forms the basis or foundation of the device. It is a rigid board with a network of copper "traces" that physically support and electrically connect all the other components. It acts as the skeleton of the device, holding everything in place and allowing for communication between parts.

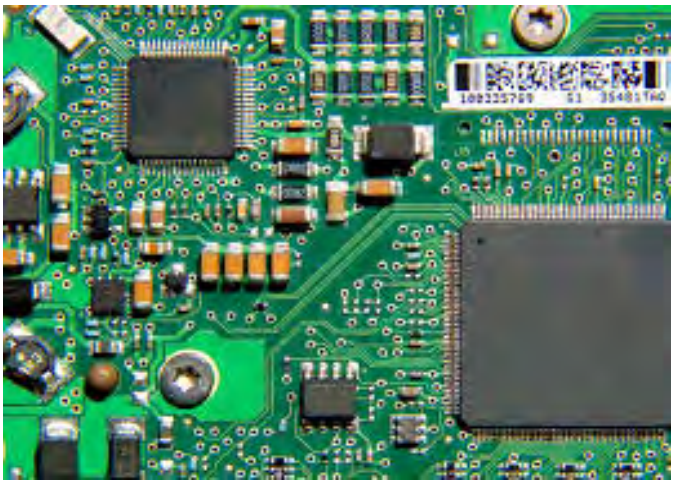


Figure 7.5: Printed Circuit Board (PCB)

Activity 7.1 Group Discussion and Mind Mapping

Aim: To identify the branches of consumer electronics devices

What you need

- Whiteboard or large paper
- Markers/pens
- Sticky notes (optional)

What to do

1. Form a small group of 3–4 members
2. Write "Consumer Electronic Devices" in the middle of your paper/board.
3. Draw three big branches: Connectivity, Convenience, Innovation.
4. Talk in your group about what each word means and how it connects to electronic devices.
5. For each branch, add examples and short explanations.
   Example: Under "Convenience" → *Microwave: quick cooking*.
6. When you are finished, turn your mind-map over. On the other side of the paper, write a single paragraph summarising the impact of consumer electronics on daily life, referencing some of your own individual experiences.
7. When time is up, choose one person to share your mind map with the larger group.

Activity 7.2 Career Path Navigator

Aim: To create a concept map for Careers in Consumer Electronics

What you need

- Large paper or whiteboard
- Markers
- Sticky notes
- Career information (internet or handouts)

What to do

1. Work in small groups.
2. Write "Careers in Consumer Electronics" in the middle of your paper.
3. Add branches for different careers (e.g., electronics technician, hardware engineer, mobile phone salesman). Try to think of at least five examples of related careers.
4. Under each career, add
   a. Skills needed

b. Main tasks
c. Parts of the devices they work on

5. Present your career map to the class.

Activity 7.3 My Device, My Life

Aim: To explore components of electronic devices.

What you need

- Your own device (optional)
- Internet or library resources
- Presentation software (PowerPoint, Google Slides)

What to do

1. Work alone or with one partner.
2. Pick a device you use often (e.g., phone, gaming console).
3. Find out:
   a. The main parts inside
   b. What each part does
   c. How they work together for one activity you do
4. Create a poster
   a. Draw or paste a big picture of the device in the centre.
   b. Around it, place smaller pictures/drawings of the parts.
   c. Label each part and write what it does.
5. Display your poster. Walk around to see other groups' work and ask questions.
6. Share your work with one other person/pair.

CAREER OPPORTUNITIES IN CONSUMER ELECTRONICS

The electronics industry is not just about designing the next smartphone. It is a vast ecosystem of roles that involve design, manufacturing, repair, sales, and support. Below are some of the key career paths you can explore.

1. **Electronics technician:** These are the problem-solvers who design, develop, install, repair and maintain the electronic devices we use daily. When a television, radio or computer malfunctions, a technician uses diagnostic tools to identify the issue and

performs the necessary repairs, which might involve replacing components or fixing faulty wiring.

2. **Hardware engineer:** A hardware engineer is an innovator who designs and develops the physical components of electronic devices. They work in teams to create circuit boards, processors, and other hardware, often using computer-aided design (CAD) software to build and test prototypes before they go into mass production.
3. **Mobile device repair specialist:** With the widespread use of smartphones and tablets, this has become a highly specialised and in-demand field. These technicians focus specifically on repairing mobile devices, handling common issues such as cracked screens, battery replacements, and water damage.
4. **Electronics sales specialist:** This role is the bridge between the product and the customer. A sales specialist works in retail environments, educating customers on the features and benefits of different devices. They need excellent communication skills and a deep understanding of the products to help customers make informed choices.
5. **Appliance technician:** Modern household appliances like refrigerators, microwaves, and washing machines are complex electronic systems. An appliance technician specialises in installing, troubleshooting, and repairing these essential home devices.
6. **Robotics or automation technician**: In an increasingly automated world, these technicians are crucial. They work with smart appliances and automated systems (such as those in smart homes or factories), programming their functions, performing routine maintenance, and troubleshooting issues to keep them running smoothly.
7. **Product tester / Quality Control (QC) officer:** Before any gadget reaches the market, it must be thoroughly tested. A QC officer ensures that products meet all safety, quality, and functionality standards. They follow strict testing protocols to identify defects, ensuring the final product is safe and reliable for consumers.
8. **Consumer electronics marketer:** This professional is responsible for creating excitement and demand for electronic products. They develop marketing campaigns, manage social media promotions, and create advertising materials to reach potential customers and communicate the value of the devices.
9. **IoT (Internet of Things) technician:** The "Internet of Things, IoT" refers to the network of interconnected smart devices. An IoT technician installs, manages, and secures these systems, such as smart home setups that connect lighting, security cameras, and speakers, ensuring they work together seamlessly.
10. **Entrepreneur in electronics repair/assembly:** For those with a business mindset, starting their own electronics company is a viable path. This could be a local repair shop, a service for custom-building computers, or a small-scale assembly business. This requires both technical skills and business knowledge in areas like customer service, marketing, and finance.

Addressing misconceptions

It is common to have preconceived notions about certain career fields. A key part of learning is to identify and correct these misconceptions with factual information.

Table 7.1: Common misconceptions and their corrections

Common misconception	Corrected misconception
1. Electronics is a job for only men.	This is incorrect. Careers in electronics are for everyone, regardless of gender. Success in this field depends on interest, skill, and dedication. Many successful female engineers, technicians, and entrepreneurs are leading figures in the industry.
2. All electronics work is dangerous.	While working with electricity has potential risks, the industry is highly regulated. With proper training, safety protocols, and the use of protective equipment, the work is very safe.
3. You need a university degree for any good job in electronics.	This is untrue. While some roles, like Hardware Engineer, require a university degree, many high-demand and well-paying roles, such as Electronics Technician or Mobile Repair Specialist, require technical or vocational training from a specialised college. There are multiple paths to a successful career.
4. All electronic components are basically the same.	As learned in the previous chapter, every component has a unique and specific function. A processor acts as the brain, a capacitor stores energy, and a resistor controls current. A device can only work when all these distinct parts function together correctly.
5. You cannot repair modern devices, so you should just throw them away.	Many devices are designed to be repairable, and a skilled technician can often fix them for a fraction of the cost of a new one. Repairing devices is also environmentally responsible as it reduces electronic waste (e-waste).

REVIEW QUESTIONS

1. Explain the functions of any five components of consumer electronic devices.
2. Describe any four careers in electronics that will inspire a prospective learner to go into that discipline.
3. List at least four misconceptions associated with the study of electronics and suggest ways of correcting them.



SECTION

8

HEREDITY

RELATIONSHIPS WITH THE ENVIRONMENT

Concept of Heredity

INTRODUCTION

Genetics is the study of heredity, exploring how traits or characteristics are passed from parents to their offsprings through genes. Do you want to know the science behind why you might have your mom's eye or your dad's hair colour? Join me as we explore the concept of heredity.

Heredity is the process through which traits or characteristics are passed from parents to their offsprings. These traits are determined by genes which are tiny units made of DNA in our cells. Genes control everything from our eye colour to how our body functions, and they are inherited from both the mother and father.

In heredity, children get a mixture of genes from both parents. Some characteristics are controlled by dominant genes, which are more likely to show up in the child. While others are controlled by recessive genes which only show up if both parents pass them down.

Understanding heredity is important in genetics because it helps predict the likelihood of certain characteristics appearing in future generations.

KEY IDEAS

- **Heredity and Genes**: Heredity is the passing of traits from parents to offspring through genes. Genes are small units of DNA that determine characteristics like eye and hair colour.
- **Dominance and Recessiveness:** Traits are controlled by dominant and recessive genes. Dominant genes are more likely to appear in the offspring, while recessive genes only appear if both parents pass them down.
- **Mendel's Law of Dominance:** This law states that in a cross between two parents with contrasting traits, only the dominant trait will appear in the F1 generation. The recessive trait is masked but can reappear in later generations
- **Mendel's Law of Segregation**: During the formation of gametes (reproductive cells), the two alleles for a trait separate from each other, so each gamete receives only one allele.
- **Mendel's Law of Independent Assortment**: Alleles for different traits segregate independently during gamete formation. This means the inheritance of one trait does not affect another, leading to more genetic variation in offspring.
- **Polygenic Inheritance**: Many complex traits, such as human height and skin colour, are controlled by multiple genes. This results in a continuous range of phenotypes rather than distinct categories.

SOME COMMON TERMS USED IN GENETICS

These terms provide a foundational understanding of genetics and are essential for studying the inheritance of traits and genetic variation.

1. **Chromosomes:** These are thread-like structures made up of nucleic acids (DNA) and proteins. They are mostly found in the nucleus of the cells. They carry the hereditary or genetic information in the form of genes. Humans have 46 chromosomes (23pairs). They determine genetic traits and biological sex (XX for females, XY for males)

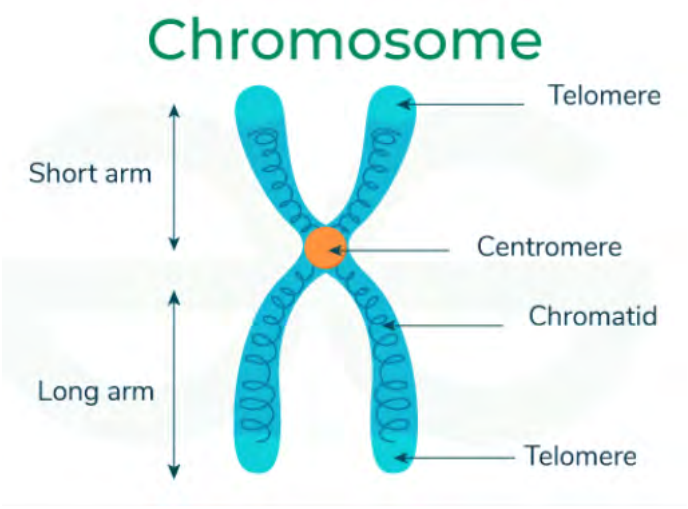


Figure 8.1: Chromosome

2. **Gene:** A small part of DNA that contains or gives instructions for building a specific protein or traits performing a specific function in an organism. Or basic units of inheritance responsible for the transmission of characters from parents to offspring.

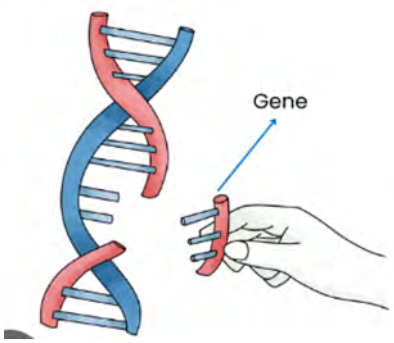


Figure 8.2: A gene

3. **Allele**: Different forms or variants of a gene. Alleles can be dominant or recessive. They are inherited in pairs – one from each parent.

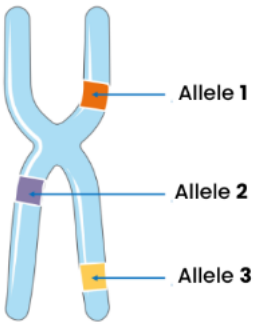


Figure 8.3: An Allele

4. **Genotype:** The genetic makeup of an organism, often represented by the combination of alleles for a particular gene. They determine inherited traits
5. **Phenotype:** The observable physical or biochemical characteristics of an organism, which result from the interaction of its genotype with the environment (diet, lifestyle, climate).
6. **Homozygous:** When an individual has two identical alleles for a particular gene

(e.g., AA or aa).

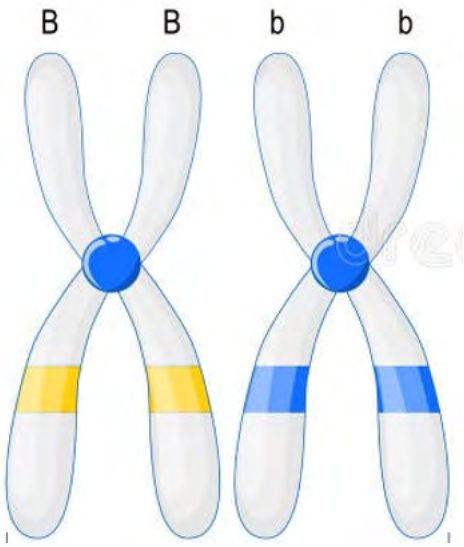


Figure 8.4: Homozygous

7. **Heterozygous**: When an individual has two different alleles for a particular gene (e.g., Aa).
8. **Dominant:** An allele that, when present, will determine the phenotype, even if a recessive allele is also present. They override or mask the effect of recessive allele in heterozygous pairing. Dominant alleles are typically represented with capital letters (e.g., A).
9. **Recessive:** An allele that is only expressed when two copies are present (homozygous). Recessive alleles are typically represented with lowercase letters (e.g., a).

10. **DNA (Deoxyribonucleic Acid):** The molecule or a material in your cells that carries all your genetic information
11. **Mutation:** A permanent change in the DNA sequence of an organism. Mutations can be beneficial, harmful, or have no effect on an organism.
12. **Genetic Trait:** A specific characteristic or feature (ranging from physical features to behavioural tendencies) that is determined by one or more genes. They are passed from parents to offspring
13. **Codominance:** When two different alleles for a gene are both fully and equally expressed in the heterozygous phenotype. The offspring displays both parental traits simultaneously rather than a blended intermediate.
14. **Incomplete Dominance:** When the phenotype of a heterozygous individual is intermediate between the two homozygous forms. Neither allele is fully dominant over the other. This results in a heterozygous phenotype that is a blend that is distinct from homozygous parents. For example, in incomplete dominance, a red flower crossed with a white flower might produce pink flowers.
15. **Pedigree:** A chart or family tree that tracks the inheritance of a particular trait through generations.
16. **Genetic Disorder:** A condition caused by abnormal or mutated genes, leading to health problems or abnormal traits. Examples include cystic fibrosis, Down syndrome, and sickle cell anaemia.
17. **Filial generation:** The offspring of parents make up the filial generation. The first, second and third generations of offspring are known as the first, second and third filial generations respectively and denoted by the symbols F1, F2 and F3 respectively, too.

Heritable / Inheritable Characters Or Traits In Human Beings

In both humans and plants, only traits that are part of the genetic makeup of the parents can be transmitted and expressed in the offspring. In humans, these inheritable traits include physical features such as skin colour, eye colour, hair colour and texture, body size and stature, shape of the head, ears, mouth, lips, and nose, as well as the length of the neck, arms, and legs. Other transmissible traits include blood group, baldness, tongue rolling ability, voice tone, intelligence, temperament, attitude, and certain genetic disorders like sickle cell anaemia and haemophilia. Some of these traits are controlled by single genes, while others are polygenic or influenced by environmental factors. These traits are passed on through genetic inheritance and can be selectively bred for desirable characteristics.

Activity 8.1 Match & Explain

In a small group with 5 classmates, perform this activity.

What you need

- Manila Card/Printed cards

- Makers/Pens
- Scissors

What to do

1. Revisit your Year 2 work on Reproduction in Humans.
2. Create 10 sets of 3 blank cards. For each set, write the name of a reproductive organ (e.g. uterus) or a process (e.g. ovulation) on one, the definition of this on another and a diagram demonstrating it on another.
3. Place the cards face up on the ground and mix them all up so that they are randomly distributed.
4. Present the cards to another team to solve by putting them back into their sets. Equally, you should solve the cards that another team has made.

Key questions

a. What happens if ovulation does not occur?

b. Why is the uterus lining important?

Activity 8.2 Exploring Human Inheritance – Traits in Your Family

In a small group with 4 classmates, perform this activity

Aim: To investigate how certain human traits are inherited and apply knowledge of genetics to understand patterns of inheritance.

What you need

- Pen/pencil
- Worksheet or notebook
- Mirror (for observing your own traits)
- Optional: Photos of family members (for trait comparison)

What to do

1. **Trait Survey**: Observe the following traits in yourself and **at least 2 biological family members** (e.g., parents or siblings)

Trait	You	Family Member 1	Family Member 2
Earlobes (Attached/Free)			
Tongue rolling (Yes/No)			
Dimples (Yes/No)			
Widow's peak (Yes/No)			
Hitchhiker's thumb (Yes/No)			

2. Record your data.
3. Fill in the table with what you observe.

Key questions (Write down your answer in your notebook)

a. Which of your traits are dominant?

b. Are there traits you have that neither parent has? If so, how might that be explained?

c. Using a **Punnett square**, predict the possible genotypes and phenotypes for **one trait** (e.g., tongue rolling) based on your parents' traits.

Worked Example

If one parent is **heterozygous (Rr)** and the other is **homozygous recessive (rr)**:

	R	r
r	Rr	rr
r	Rr	rr

Genotype Ratio: 2 Rr: 2 rr

Phenotype Ratio: 2:2

CHARACTERS OR TRAITS ARE TRANSMITTED FROM GENERATION TO GENERATION

Inherited characters are determined by genes, which are segments of DNA located on chromosomes. In diploid organisms, with two sets of chromosomes, each gene exists in two copies, located at identical positions (called loci) on homologous chromosome pairs. These organisms produce reproductive cells, or gametes, through a process called meiosis, which occurs in their reproductive organs.

During meiosis, the number of chromosomes is halved, resulting in haploid gametes: sperm cells in males and egg cells in females. Each gamete contains only one set of chromosomes and thus only one copy of each gene.

During sexual reproduction, a male and a female gamete fuse in a process called fertilisation to form a zygote, which is diploid, receiving one set of chromosomes from each parent. This is how genes, and the traits they control, are transmitted from parents to offspring. The individuals that produce gametes make up the parental (P) generation, while their offspring are referred to as the first filial (F1) generation.

The process of mating or sexual union is called a cross (represented as "×"). A gene controlling a particular trait may exist in alternative forms called alleles, which may result in different expressions of the trait.

The science of heredity and genetic inheritance was founded by Gregor Mendel (1822–1884), who is regarded as the father of genetics. Mendel conducted experiments using pea plants and developed the principles of inheritance using two main methods: monohybrid inheritance, which involves a single pair of contrasting traits, and dihybrid inheritance, which involves two pairs of contrasting traits.

Through his work, Mendel established the foundational laws of inheritance that explain how traits are passed from generation to generation.

Inheritance of one Gene (Monohybrid Inheritance)

Gregor Mendel, often hailed as the "father of genetics," laid the foundational principles of heredity through his experiments with garden pea plants (*Pisum sativum*).

His studies on monohybrid inheritance involved crossing plants that differed in only one specific, contrasting character at a time, such as tall versus short plant height. These experiments provided crucial insights into how traits are passed from one generation to the next.

The Parental (P) Generation Cross

Mendel began his experiments with true-breeding (or purebred) pea plants. A true-breeding plant consistently produces offspring identical to itself when self-pollinated over many generations, ensuring that it carries only one type of allele for the trait in question. For his monohybrid cross focusing on plant height, Mendel selected:

a. **True-breeding tall pea plants:** These plants always produce tall offspring when self-pollinated. Their genetic makeup for height can be represented as TT (homozygous dominant).
b. **True-breeding dwarf pea plants:** These plants always produced dwarf offspring when self-pollinated. Their genetic makeup can be represented as tt (homozygous recessive).

Mendel then performed an artificial cross-pollination (or hybridization) between these two contrasting true-breeding parental types. He carefully transferred pollen from the flowers of a tall plant to the stigma of a dwarf plant (and vice-versa, performing reciprocal crosses to ensure the results were consistent regardless of which parent contributed the pollen).

The First Filial (F1) Generation: A Glimpse of Dominance

The seeds resulting from this initial cross were collected and planted to grow the F1 generation (First Filial generation). Mendel observed a striking and consistent result: all the plants in the F1 generation grew to be tall**.**

This observation was groundbreaking because the dwarf trait seemed to have disappeared entirely.

Mendel deduced that one trait must be "masking" or "dominating" the other. He termed the trait that was expressed in the F1 generation (tallness) the dominant trait**,** and the trait

that disappeared (dwarfness) the recessive trait. Using his symbolic representation, if 'T' represents the allele for tallness and 't' represents the allele for dwarfness:

a. The true-breeding tall parent contributed only 'T' alleles to its gametes.
b. The true-breeding dwarf parent contributed only 't' alleles to its gametes.
c. Therefore, all F1 offspring inherited one 'T' allele from the tall parent and one 't' allele from the dwarf parent, resulting in a heterozygous genotype of Tt.
d. Despite having the 't' allele, all F1 plants were phenotypically tall, identical to the homozygous dominant (TT) parent, confirming the dominance of the 'T' allele.

The Second Filial (F2) Generation: The Principle of Segregation Unveiled

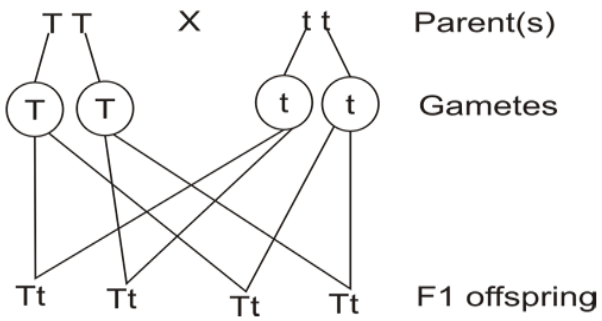
To further investigate why the dwarf trait reappeared, Mendel allowed the plants of the F1 generation to self-pollinate. The seeds produced from these self-pollinating F1 plants were then collected and planted, giving rise to the F2 generation (Second Filial generation). The results from the F2 generation were even more revealing:

a. In the F2 generation, Mendel observed both tall plants and dwarf plants.
b. Crucially, he found that these traits appeared in a remarkably consistent ratio: approximately three-quarters (¾) of the plants were tall, and one-quarter (¼) of the plants were dwarf. This is famously known as the 3:1 phenotypic ratio for a monohybrid cross.

This re-emergence of the recessive dwarf trait in the F2 generation, after its complete absence in the F1, led Mendel to propose the Law of Segregation. This law states that during gamete formation, the two alleles for a heritable character (e.g., T and t) separate (segregate) from each other so that each gamete carries only one allele.

When the F1 plants (Tt) self-pollinate, their gametes (T and t) randomly combine, leading to the observed 1:2:1 genotypic ratio (TT: Tt: tt) and the 3:1 phenotypic ratio in the F2 generation.

Mendel's monohybrid crosses, with their simple design and clear mathematical ratios, provided the foundational evidence for the existence of discrete heritable factors (what we now call genes and alleles) and established the basic rules by which these factors are transmitted from one generation to the next.



The genotype for F1 is Tt

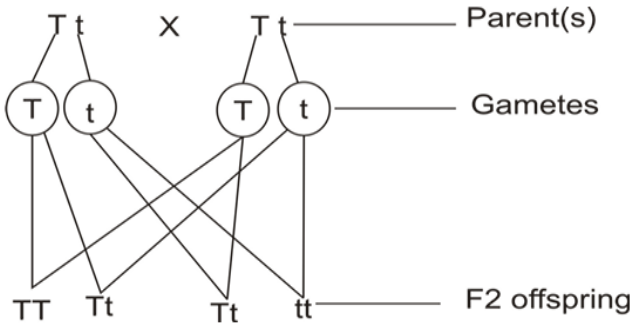
The phenotype: all tall, but they are heterozygous (not pure breed). From this he concluded that T is the dominant allele which expresses itself irrespective of the second allele present.

In F2 generation, tall plants with genotype TT and Tt appeared while dwarf plants with tt gene appeared. He concluded that 't' is the recessive allele and it can only express itself in the presence of the same recessive allele. Mathematically he calculated that in F2 generation ¼ tall plants were with genotype TT while ½were Tt and ¼ were tt. However, Tt and TT was tall, so phenotypically ¾ of the plants were tall while the only ¼ of them were phenotypically and genotypically dwarf.

The phenotypic ratio was calculated to be ¾ of tall: ¼of dwarf i.e., 3: 4. The genotypic ratio was calculated to be ¼: ½: ¼ (TT: Tt: tt), i.e. 1: 2: 1.

Mendel concluded all this with the help of Punnett square. The cross explained is a monohybrid cross as inheritance of only one trait is considered at one time only. It is monohybrid and an example of complete dominance.

If there is self-pollination to obtain second generation, we get the outcome below;



Genotypic ratio: 1: 2:1

Phenotype: 3: 1

Mendel's Findings

Gregor Mendel's experiments with pea plants led to profound discoveries about heredity, which he explained through a series of observations and fundamental principles. His work, though initially overlooked, laid the foundation for modern genetics.

Summary of Mendel's Observations and Ratios

Through his monohybrid crosses (as seen with tall and dwarf pea plants), Mendel made several crucial observations:

a. **The F1 Generation's Uniformity:** When he crossed two true-breeding parents differing in a single contrasting trait (e.g., pure tall TT with pure dwarf tt), the entire First Filial (F1) generation uniformly resembled only one of the two parental traits**.** For instance, all F1 pea plants were tall, even though one parent was dwarf. This indicated that one trait was expressed while the other seemed to disappear.

b. **The F2 Generation's Re-emergence and Ratios:** When the F1 generation plants (which were all phenotypically dominant) were allowed to self-pollinate, the Second Filial (F2) generation exhibited a predictable pattern

   i. **Phenotypic Ratio:** Both the dominant and recessive forms of the trait reappeared. Roughly three-quarters (¾) of the F2 plants displayed the dominant phenotype (e.g., tall), while one-quarter (¼) displayed the recessive phenotype (e.g., dwarf). This established a consistent 3:1 phenotypic ratio (dominant: recessive).

   ii. **Genotypic Ratio:** Further analysis (later confirmed by test crosses) revealed that the F2 generation possessed a specific genotypic ratio of 1:2:1. This ratio represented 1-part homozygous dominant (e.g., TT), 2 parts heterozygous (e.g., Tt), and 1-part homozygous recessive (e.g., tt). This showed that while the outward appearance (phenotype) was 3:1, the underlying genetic makeup (genotype) was more varied.

Interpretation of Mendel's Results

Mendel's genius lay not just in his careful experiments but also in his ability to interpret these numerical patterns. He proposed that hereditary characteristics are controlled by discrete "factors" (what we now call genes), which are transmitted from parents to offspring. Each factor, or gene, contains specific information about a particular form of a trait. He understood that these factors exist in pairs within an individual and that they somehow separate and combine predictably.

Inheritance of Two Genes (Dihybrid Inheritance)

Following his groundbreaking work on monohybrid inheritance, Gregor Mendel further expanded his understanding of heredity by studying the simultaneous inheritance of two different traits at a time. This type of genetic investigation is known as a dihybrid cross, and it proved pivotal in formulating his second major law of inheritance.

The Parental (P) Generation Cross: Setting the Stage

Mendel began his dihybrid cross by selecting true-breeding pea plants that differed in two distinct pairs of contrasting characters. He chose:

a. **Plants with Round and Yellow seeds:** These were true-breeding for both traits, meaning they always produced round, yellow seeds when self-pollinated. Their genotype was represented as RRYY (homozygous dominant for both traits).

b. **Plants with Wrinkled and Green seeds**: These were true-breeding for their respective traits, always producing wrinkled, green seeds. Their genotype was represented as rryy (homozygous recessive for both traits).

Mendel then performed an artificial cross-pollination between these two contrasting parental types (RRYY x rryy).

The First Filial (F1) Generation: All Dominant Phenotypes

The seeds resulting from this cross were planted, yielding the F1 generation. All the plants in this F1 generation exhibited the dominant phenotype for both traits: they all produced Round and Yellow seeds.

This result was consistent with Mendel's Law of Dominance, which he had established from his monohybrid crosses. Each F1 individual inherited one allele for seed shape (R) and one for seed colour (Y) from the RRYY parent, and one allele for seed shape (r) and one for seed colour (y) from the rryy parent. This made all F1 individuals heterozygous for both traits, with a genotype of RrYy.

Gamete Formation in the F1 Generation: The Law of Independent Assortment

The most crucial stage for understanding the dihybrid cross lies in the formation of gametes by these F1 (RrYy) individuals. Here, Mendel's observations led to his second major principle: The Law of Independent Assortment.

a. **Principle**: This law states that alleles for different traits (e.g., the alleles for seed shape, R/r, and the alleles for seed colour, Y/y) segregate independently of each other during gamete formation (meiosis). This means that the inheritance of one trait does not influence the inheritance of the other trait.

b. **Mechanism:** When an F1 individual (RrYy) produces gametes, the 'R' allele segregates from the 'r' allele, and the 'Y' allele segregates from the 'y' allele. Crucially, these two segregation events happen independently. Therefore, a gamete can receive any combination of one allele from each gene pair. For example, a gamete could receive 'R' along with 'Y' (RY). Or, it could receive 'R' along with 'y' (Ry). Similarly, it could receive 'r' along with 'Y' (rY). Or, it could receive 'r' along with 'y' (ry).

c. **Gamete Ratios**: Because of independent assortment, these four types of gametes (RY, Ry, rY, ry) are produced in approximately equal proportions, each representing 25% or ¼th of the total gametes produced by an F1 (RrYy) individual.

The Second Filial (F2) Generation (The Characteristic 9:3:3:1 Ratio)

Mendel allowed the F1 (RrYy) plants to self-pollinate. The seeds produced from this self-pollination yielded the F2 generation, which displayed a variety of phenotypes, not just the two parental types. By counting the number of individuals in each phenotypic category, Mendel consistently observed a characteristic 9:3:3:1 phenotypic ratio:

a. 9 parts: Round and Yellow seeds (dominant for both traits)

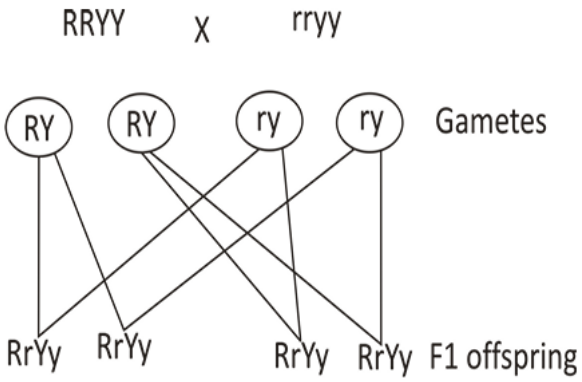
b. 3 parts: Round and Green seeds (dominant for shape, recessive for colour)

c. 3 parts: Wrinkled and Yellow seeds (recessive for shape, dominant for colour)

d. 1 part: Wrinkled and Green seeds (recessive for both traits)

This complex ratio, derived from the random combination of the four types of gametes (RY, Ry, rY, ry) in a 16-square Punnett square (an extension of the 2x2 monohybrid

square), provided strong evidence for the independent assortment of different genetic traits. It demonstrated that alleles for different genes are sorted into gametes independently of one another, leading to a wider range of phenotypic combinations in the offspring than would be possible if traits were inherited together. Mendel's dihybrid cross was a massive achievement, revealing the elegant predictability of trait transmission a round yellow and wrinkled green seeds,



F_2 cross pollinated each other

	RY	Ry	rY	ry
RY	RRYY	RRYy	RrYY	RrYy
Ry	RRYy	RRyy	RrYy	Rryy
rY	RrYY	RrYy	rrYY	rrYy
ry	RrYy	Rryy	rrYy	rryy

Interpretation of Mendel's Results

Gregor Mendel's meticulous work with pea plants led to the formulation of fundamental principles that govern how traits are passed from one generation to the next. These principles, often referred to as Mendel's Laws, alongside specific types of genetic crosses, are crucial for understanding inheritance patterns and determining the genetic makeup of individuals.

Mendel's Laws of Inheritance

a. **The Law of Dominance**: This law states that when an individual possesses two different alleles for a single inherited trait, one allele (the dominant allele) will mask the expression of the other allele (the recessive allele), determining the observable characteristic or phenotype. The recessive allele remains present in the genotype but is not expressed phenotypically. This principle is evident in the F1 generation of a monohybrid cross between two true-breeding parents. For instance, when a true-breeding tall pea plant (TT) is crossed with a true-breeding dwarf pea plant (tt), all F1 offspring are tall (Tt). The allele for tallness (T) is dominant and completely suppresses the expression of the allele for dwarfness (t) in the heterozygous state.

b. **The Law of Segregation:** This law states that during the formation of gametes (sperm and egg cells) in sexually reproducing organisms, the two alleles for a heritable character (e.g., T and t) separate (segregate) from each other so that each gamete receives only one allele. This segregation occurs during meiosis. For example, a heterozygous F1 plant (Tt) will produce two types of gametes: 50% carrying the 'T' allele and 50% carrying the 't' allele. The alleles do not blend or permanently influence each other; they remain discrete units and simply separate during gamete formation. This random segregation ensures that each offspring receives a unique combination of alleles, leading to the reappearance of recessive traits in the F2 generation.

c. **The Law of Independent Assortment:** This law states that alleles for different genes (i.e., genes controlling different traits) segregate independently of each other during gamete formation. This means that the inheritance of one trait does not influence the inheritance of another distinct trait.

This principle applies to dihybrid crosses (where two or more traits are studied simultaneously). For example, in a cross-involving seed colour (yellow/green) and seed shape (round/wrinkled), the way the alleles for colour separate into gametes is independent of how the alleles for shape separate. An individual heterozygous for both traits (RrYy) will produce gametes containing all possible combinations of alleles (RY, Ry, rY, ry) in equal proportions, as if each gene were inherited alone. This independence leads to greater genetic variation in offspring.

Determining Parental Genotypes: Back Cross and Test Cross

In genetics, it is often crucial to determine the specific genotype of an individual, particularly if they exhibit a dominant phenotype, as this phenotype can result from either a homozygous dominant (e.g., TT) or a heterozygous (e.g., Tt) genotype. This uncertainty can be resolved using specific types of genetic crosses.

1. Back Cross

A back cross is a general term for a cross where the F1 progeny (first filial generation offspring) is mated back to either one of its parentals (P) genotypes.

Back crosses are commonly used in breeding programs to introduce a specific trait from a wild relative into a cultivated crop, or to rapidly develop inbred lines (a group of genetically identical homozygous organisms produced by repeated self-fertilization between close relatives over several generations).

F_1 x Dominant Parent (e.g., Tt x TT): This type of back cross is used to quickly increase the proportion of offspring carrying the dominant allele, often seen in livestock breeding to improve desirable traits.

F_1 x Recessive Parent (e.g., Tt x tt) : This specific type of back cross is also known as a Test Cross (see below) and is particularly informative for determining genotype.

2. Test Cross

A test cross is a specialised type of back cross where an individual displaying the dominant phenotype (but of unknown genotype, e.g., T?) is crossed with a homozygous recessive individual (e.g., tt) for the same trait. The primary purpose of a test cross is to determine the unknown genotype (whether homozygous dominant or heterozygous) of the parent showing the dominant phenotype.

If the unknown parent is homozygous dominant (TT), all F_1 offspring from the test cross (TT x tt) will be heterozygous (Tt) and will express the dominant phenotype (100% dominant phenotype).

If the unknown parent is heterozygous (Tt), then crossing Tt x tt will produce offspring in a 1:1 phenotypic ratio of dominant to recessive traits (e.g., 50% tall (Tt) and 50% dwarf (tt)).

The appearance of any recessive offspring immediately reveals that the unknown parent must have been heterozygous. Test crosses are widely used in agriculture (plant and animal breeding) to confirm the genetic purity of breeding lines or to identify desirable heterozygotes.

Polygenic Inheritance

Polygenic Inheritance: The Basis of Continuous Variation

Beyond the simple inheritance patterns described by Mendel's monohybrid and dihybrid crosses, many complex traits in organisms are influenced by the combined action of multiple genes. This phenomenon is known as polygenic inheritance.

Polygenic inheritance occurs when the expression of a single phenotypic trait is controlled by the collective effect of more than one gene. These genes are often located at different loci (positions) on the same or different chromosomes. Because multiple genes are involved, this mode of inheritance is also referred to as quantitative inheritance or multiple factor inheritance.

Characteristics of Polygenic Traits

Polygenic traits exhibit several distinctive features that differentiate them from Mendelian traits (which are typically controlled by a single gene):

1. **Continuous Variation**: Unlike Mendelian traits that usually fall into distinct categories (e.g., tall or dwarf, yellow or green), polygenic traits show a continuous range or spectrum of phenotypes within a population. This variation can be measured and often follows a bell-shaped curve (normal distribution). There are many intermediate forms between the two extremes.
2. **Additive Effect of Alleles:** The genes involved in polygenic inheritance typically contribute to the phenotype in an additive manner. This means that each "contributing allele" (often the dominant allele) adds a small, incremental, or cumulative effect to the phenotype. The more contributing alleles an individual possesses, the more pronounced

the trait becomes. There is generally no complete dominance or recessiveness among the individual alleles across all the genes involved; rather, their effects sum up.

3. **Multifactorial Influence (Gene-Environment Interaction):** Many polygenic traits are also multifactorial traits. This implies that while multiple genes play a significant role, environmental factors (such as nutrition, lifestyle, exposure to sunlight, disease) can also interact with the genetic predisposition to modify the final phenotype. The environment can either enhance or diminish the expression of the genetic potential.

Examples of Polygenic Inheritance in Humans

Human traits provide excellent illustrations of polygenic inheritance.

1. **Height:** Human height is a classic example of a polygenic trait. We do not observe just two distinct categories like "tall" and "short" in the population. Instead, there's a wide range of heights, from very short to very tall, with many intermediate measurements.

This continuous variation reflects the influence of hundreds of genes, each contributing a small amount to an individual's adult height.

An individual's height depends on the cumulative effect of the "tall" alleles inherited from both parents across these numerous genes (Additive Effect).

While genetics sets the potential range, environmental factors like adequate nutrition during growth, lack of chronic illness, and general health significantly influence whether an individual reaches their full genetic height potential

2. **Skin Colour:** Human skin pigmentation is another well-known example of polygenic inheritance, determined by the amount and type of melanin produced in the skin. It is influenced by multiple gene pairs (often modelled with three, but potentially up to six or more genes in reality) that contribute to melanin production. Using a simplified model with three gene pairs (A/a, B/b, C/c), where uppercase alleles (A, B, C) contribute to darker skin (more melanin) and lowercase alleles (a, b, c) contribute to lighter skin (less melanin):

    a. The genotype aabbcc would represent the very lightest skin colour (zero contributing alleles). The genotype AABBCC would represent the very darkest skin colour (six contributing alleles). All other combinations represent intermediate shades.

    b. For example, a person with genotype AaBbCc (three contributing alleles) would have a medium skin tone. A person with AABbcc (four contributing alleles) would be darker than medium but lighter than AABBCC. The effect of each contributing allele is additive, meaning the total number of uppercase alleles directly correlates with the degree of skin pigmentation.

    c. This additive effect across multiple genes results in the vast and continuous spectrum of human skin colours observed globally, from very light to very dark, with countless intermediate shades (Continuous Spectrum). Environmental factors like sun exposure (tanning) can further modify the expressed phenotype of skin colour, highlighting its multifactorial nature.

UNDERSTANDING HEREDITARY DISEASES IN HUMANS

Have you ever wondered why certain diseases seem to "run in families"? Maybe you've heard someone say, "Diabetes runs in my family" or "My mom and grandma both had breast cancer." These are examples of what scientists call **hereditary diseases;** health conditions that are **passed from parents to their children through genes**.

To understand hereditary diseases, we first need to understand a bit about **genetics.** Every human has **DNA**, which contains **genes**; the instructions that determine everything from our eye colour to how our bodies work. We inherit half of our genes from our mother and the other half from our father. Sometimes, genes can carry **mutations,** or small changes, that may cause a disease. If these faulty genes are passed on to children, they can also inherit the risk of developing the same disease.

KEY IDEAS

- How genes and inheritance work
- Examples of common hereditary diseases
- Types of Hereditary diseases

The Role of Genes in Heredity

Heredity is the process by which traits and characteristics are passed from parents to their children. This happens through **genes**, which are small sections of DNA found in our chromosomes. Genes carry the instructions for how our bodies grow, develop, and function.

Each person inherits two copies of every gene; one from their mother and one from their father. Sometimes, changes or mutations in these genes can lead to **genetic disorders.** These disorders can be passed down from generation to generation, depending on how the faulty gene is inherited.

Examples of Hereditary Diseases

a. **Cystic Fibrosis:** a recessive disorder (genetic condition that occurs when an individual inherits two nonworking copies of a gene – one from each parent) that affects the lungs and digestive system.

b. **Huntington's Disease:** a dominant disorder (genetic disorder caused by the mutation in one copy of a gene from either parent) that affects the brain and movement**.** The mutation is caused on a non-sex chromosome

c. **Haemophilia**: an X-linked disorder (genetic condition caused by the mutations in genes on the X chromosomes) that affects the blood's ability to clot.

Types of Hereditary Diseases

1. **Single-Gene (Monogenic) Disorders**: These are caused by changes (mutations) in just **one gene.** The disorder can be inherited in different ways:
    a. **Dominant**: One copy of the faulty gene causes the disease. *Example: Huntington's disease*
    b. **Recessive**: Two copies of the faulty gene are needed. *Example Cystic fibrosis*
    c. **X-linked**: The gene is on the X chromosome. *Examples Haemophilia, Duchenne muscular dystrophy etc.*
2. **Chromosomal Disorders**: These are caused by **problems (abnormalities) with whole chromosomes**; such as missing, extra, or broken chromosomes. *Examples are Down syndrome and Turner syndrome.*
3. **Multifactorial (Complex) Disorders**: These are caused by a **combination of genes and environmental factors,** such as lifestyle or diet. They don't follow simple inheritance patterns. *Examples are heart disease diabetes and some types of cancer, etc.*

There are various inheritance patterns that determine how hereditary diseases are passed on. In some cases, a person can carry a gene with a defect without experiencing any symptoms; this is known as being a carrier. This happens because the normal version of the gene can compensate for the defective one. However, if a child inherits two defective copies of a gene (one from each parent), they are likely to develop the associated disorder.

This explains why sometimes a child can be born with a genetic disease even when neither parent shows any signs of illness. The condition only manifests when both parents unknowingly carry the same defective gene and pass it on to their child. This pattern is common in recessive genetic disorders.

Examples of Hereditary Diseases

There are many well-known examples of hereditary diseases. These include:

a. **Hereditary Hemochromatosis:** a disorder causing the body to absorb too much iron, leading to organ damage.
b. **Down Syndrome:** a chromosomal condition caused by an extra copy of chromosome 21, leading to developmental delays and physical characteristics.
c. **Sickle Cell- anaemia:** a blood disorder where red blood cells are abnormally shaped, leading to pain and reduced oxygen transport.
d. **Turner Syndrome:** a chromosomal condition affecting females, where one of the X chromosomes is missing or incomplete, impacting growth and development.

Some Other Types of Hereditary Diseases and Organs Affected

1. Cystic Fibrosis

Cystic Fibrosis (CF), also known as mucoviscidosis, is a serious, inherited genetic disorder that profoundly impacts the body's exocrine glands. It leads to the production of abnormally thick, sticky mucus and excessively salty sweat. This viscous mucus obstructs various ducts and passageways, particularly in the respiratory, digestive, and reproductive systems, leading to a range of complications. CF is caused by a defect in the Cystic Fibrosis Transmembrane Conductance Regulator (CFTR) gene.

This gene provides instructions for creating the CFTR protein, which acts as a channel controlling the movement of chloride ions and water in and out of cells. In individuals with CF, the mutated CFTR gene produces a faulty protein that either doesn't work correctly or isn't produced at all. This dysfunction disrupts the delicate balance of salt and water transport, causing secretions (like mucus, sweat, and digestive juices) to become dehydrated, thick, and sticky.

Instead of acting as lubricants, these secretions plug up tubes and ducts, leading to significant organ damage over time.

2. Organs Affected

a. **Lungs:** The thick mucus clogs the small airways, making it difficult to breathe and creating an ideal environment for bacterial infections. This leads to chronic lung infections, inflammation, and progressive lung damage, including bronchiectasis (widening of the airways).

b. **Pancreas:** The mucus blocks the ducts that carry digestive enzymes from the pancreas to the small intestine. This prevents proper digestion and absorption of fats, proteins, and vitamins, leading to malnutrition, poor growth, and sometimes cystic fibrosis-related diabetes (CFRD).

c. **Intestines:** Blockages can occur, particularly in newborns (meconium ileus) and older children/adults (distal intestinal obstruction syndrome), causing severe constipation and abdominal pain.

d. **Liver:** Blockage of bile ducts can lead to inflammation and scarring (cirrhosis) in a small percentage of individuals.

e. **Sweat Glands:** The faulty CFTR protein also affects sweat glands, leading to abnormally salty sweat. This is a key diagnostic indicator.

f. **Reproductive System:** In men, thick mucus can block or cause the absence of the vas deferens (the tube that carries sperm), leading to infertility in almost all cases. Women with CF may experience reduced fertility but can often conceive and have successful pregnancies.

3. Down Syndrome

Down syndrome, also known as Trisomy 21, is a genetic condition caused by the presence of extra genetic material from chromosome 21. This chromosomal abnormality results in

a unique set of physical characteristics, intellectual disabilities, and developmental delays, the severity of which can vary significantly among individuals. It is the most common chromosomal disorder leading to intellectual disability in children.

Causes of Down Syndrome

Down syndrome is caused by abnormal cell division that leads to an extra full or partial copy of chromosome 21. While the exact reason for these cell division errors is not fully understood, they can occur in one of three ways:

a. **Trisomy 21 (Nondisjunction):** This is the most common cause, accounting for about 95% of Down syndrome cases. In Trisomy 21, an individual has three copies of chromosome 21 in every cell of their body, instead of the usual two. This occurs due to an error in cell division during the formation of the sperm or egg cell (meiosis), where a pair of chromosomes 21 fails to separate. When this egg or sperm fuses with a normal gamete, the resulting embryo has three copies of chromosome 21.

b. **Mosaic Down Syndrome**: This is a rare form of Down syndrome, affecting about 1% of individuals with the condition. In mosaic Down syndrome, a person has a mix of cells, some with the usual two copies of chromosome 21 and others with three copies. This "mosaic" pattern is caused by an abnormal cell division error that occurs after fertilization, early in embryonic development. Individuals with mosaic Down syndrome may have fewer characteristics of Down syndrome than those with Trisomy 21 because of the presence of some normal cells.

c. **Translocation Down Syndrome**: This form accounts for about 4% of Down syndrome cases. In translocation Down syndrome, part of chromosome 21 breaks off during cell division and attaches (translocate) to another chromosome, most commonly chromosome 14, 21, or 22. Individuals with translocation Down syndrome have the usual two full copies of chromosome 21, but they also have extra genetic material from chromosome 21 attached to another chromosome. This can occur spontaneously or, rarely, can be inherited from a parent who is a "balanced carrier" of the translocation. A balanced carrier has the rearranged chromosome but no extra or missing genetic material, so they do not have Down syndrome themselves, but they can pass on the unbalanced translocation to their children. Only about one-third of translocation Down syndrome cases are inherited.

4. Asthma

Asthma is a long-term (chronic) condition that affects the **lungs**. It makes it **hard to breathe** because the airways (tubes that carry air in and out of the lungs) become;

a. **Swollen** (inflamed)

b. **Tight** (the muscles around the airways squeeze)

c. **Full of mucus** (a sticky substance)

What Triggers Asthma?

A **trigger** is something that causes asthma symptoms to start or get worse.

Common triggers:

a. Dust, pollen, mould, pet hair
b. Cold air
c. Smoke or pollution
d. Exercise
e. Strong smells (like perfume or cleaning chemicals)
f. Stress or strong emotions
g. Infections (like a cold or flu)
h. Some medicines (like aspirin)

Common Symptoms of Asthma:

a. Shortness of breath
b. Wheezing (whistling sound when breathing)
c. Chest tightness
d. Coughing, especially at night or early morning

Asthma symptoms can come and go. Sometimes, the symptoms get worse very quickly — this is called an **asthma attack**

Types of Asthma

Asthma is not the same for everyone. There are different **types**, depending on what causes it or how it shows up.

a. **Allergic Asthma**: Caused by allergies (e.g., dust, pollen, animals)
    i. Usually starts in childhood
    ii. Often linked to other allergic problems like eczema or hay fever
b. **Non-Allergic Asthma**: Not caused by allergies.
    i. Triggered by smoke, cold air, stress, or illness
    ii. More common in adults
c. **Exercise-Induced Asthma**
    i. Triggered by physical activity or sports
    ii. You may feel breathless or start coughing during or after exercise
d. **Occupational Asthma**
    i. Caused by breathing in chemicals or dust at work
    ii. Gets better when you're away from work
e. **Cough-Variant Asthma**
    i. The main symptom is a **dry cough**
    ii. There's usually no wheezing

f. **Aspirin-Induced Asthma**

   i. Triggered by taking aspirin or certain painkillers
   ii. Often happens with sinus problems or nasal polyps

g. **Nocturnal Asthma**: Symptoms get worse at **night** while you are sleeping

   h. **Severe Asthma**
   i. Hard to control even with strong medication
   ii. Needs special treatment from a doctor

Activity 8.3 Exploring a Sex-Linked Recessive Hereditary Disorder

Perform this activity in a group of five members or alone.

Aim: To analyse real-life case studies to understand the symptoms, progression and impact of hereditary disease

What you need

- A printout of a simplified real-life story with details of family history, early symptoms, diagnosis process and impact on lifestyle and family dynamics.
- Notebooks
- **Pen/Pencils**

What to do

1. **Analyse this real-life scenario carefully about a 15-year-old boy**
2. Use these questions as a guide, discuss and write down your findings for presentation after analysing the scenario.
   a. What clues suggested the 15-year-old boy might have a genetic disorder?
   b. How is haemophilia inherited? Draw a Punnett square using an X-linked trait?
   c. How did his condition affect his daily life and emotional well-being?
   d. How did the family respond, and what support systems helped them?
   e. What advice would you give to the boy or his family?

The Scenario: Background & Family History

A 15-year-old boy from the Eastern Cape. He lives with his mother, grandmother, and younger sister. His family never knew that haemophilia ran in their bloodline, but his mother recalls that her younger brother died from internal bleeding after a minor accident when he was a teenager. At the time, no one knew the cause.

Because **haemophilia is inherited through the X chromosome,** his mother is likely a **carrier** and unknowingly passed the faulty gene to her son.

Early Symptoms

When he was about 2 years old, his mother noticed that he would

a. Bleed from the gums during brushing that took a long time to stop.
b. Have painful swelling in his knees and elbows after playing or falling.

At age 4, he suffered a nosebleed that lasted for almost an hour. That is when his mother decided to take him to a doctor specialist.

Diagnosis Process

The doctor rans blood tests and found that his blood lacked a protein called **Factor VIII**, which is needed for proper blood clotting. He was diagnosed with **Haemophilia A** – a lifelong, genetic condition. They were referred to a genetic counsellor who explained to the mother that;

a. The disease is **X-linked recessive**.
b. Since her son is male (XY), he got the faulty gene from his mother (a carrier).
c. His sister may also be a carrier, and might one day pass it on to her children.

Impact on Lifestyle

The young boy now has to make many adjustments:

a. He avoids contact sports and rough play.
b. He receives **regular injections** of clotting factor at a clinic.
c. He wears a **medical bracelet** in case of emergencies.
d. His family has learned to treat cuts quickly and monitor swelling and bruises closely.

He sometimes feels isolated when his friends play soccer, and he can't join. He also misses school during hospital visits, which affects his academics.

Impact on Family Dynamics

His diagnosis changed the way the whole family lives:

a. His mother became more protective and sometimes overly cautious, which frustrates him

b. The family had to budget for transport and occasional private healthcare when government clinics were full. c. His sister became more curious about genetics and now wants to become a nurse.

d. The family is now more educated about hereditary diseases and is considering **genetic testing and counselling** for future family planning.

Activity 8.4 Understanding Heredity Disease through Research and Real–life Stories

Aim: To research hereditary diseases

What you need

- For research (Notebooks, test books or internet)
- For presentation (Poster papers, makers.

What to do

1. In groups of 3-5, choose a hereditary disease, for example: Cystic Fibrosis, Sickle Cell, Anaemia, Haemophilia, etc.
2. Each group must research genetic causes, inheritance patterns, symptoms, age of onset, and available treatments.
3. Write down your findings to create a visual aid for presentation.

DIABETES MELLITUS

Diabetes Mellitus (DM) is a chronic metabolic disorder characterised by high levels of glucose (sugar) in the blood. This condition arises either because the body **does not produce enough insulin** or because the body **cannot effectively use the insulin it produces.**

Glucose is a primary source of energy for the body's cells, and insulin is the hormone that allows glucose to enter the cells. When insulin is lacking or not functioning properly, glucose accumulates in the bloodstream instead of being used by the cells for energy.

The Role of Insulin

Insulin is a hormone produced by the **beta cells** in the pancreas (specifically in the islets of Langerhans). It plays a central role in regulating blood glucose levels.

Functions of Insulin

a. Facilitates glucose uptake by cells (especially muscle and fat cells).

b. **Stimulates the liver** to store excess glucose as **glycogen**.
c. **Inhibits glucose production** by the liver.
d. Promotes the storage of **fats** and **protein synthesis.**

When insulin is **absent or not working properly**, the following occurs:

a. Glucose stays in the blood which result in **hyperglycaemia** (high blood sugar).
b. Cells are starved of energy despite plenty of glucose being available.
c. Over time, this leads to serious damage to the heart, blood vessels, eyes, kidneys, and nerves.

Types of Diabetes Mellitus

There are several types of diabetes, but the main ones are:

A. Type 1 Diabetes Mellitus (T1DM)

Cause: Autoimmune destruction of pancreatic beta cells → little or no insulin production.

Onset: Usually develops in childhood or adolescence, but can occur at any age.

Insulin-dependent: Patients need **lifelong insulin therapy**.

Symptoms Of Type 1 Diabetes Mellitus

a. Rapid weight loss
b. Fatigue
c. Frequent urination (polyuria)
d. Excessive thirst (polydipsia)
e. Increased hunger (polyphagia)

B. Type 2 Diabetes Mellitus (T2DM)

Cause: The body becomes **resistant to insulin**, and the pancreas cannot make enough insulin to overcome this resistance.

Onset: Most common in adults over 40, but increasingly seen in children due to obesity and sedentary lifestyle.

Risk Factors

a. Obesity
b. Physical inactivity
c. Family history
d. Unhealthy diet

Managed by

a. Lifestyle changes (diet, exercise)
b. Oral medications
c. Sometimes, insulin therapy if required

Gestational Diabetes Mellitus (GDM)

Occurs during pregnancy, usually in the second or third trimester.

Cause: Hormones from the placenta interfere with the action of insulin.

Usually resolves after birth, but it increases the mother's risk of developing type 2 diabetes later.

Risks to the baby

a. High birth weight
b. Preterm birth
c. Low blood sugar after birth

Managed by

a. Lifestyle changes (diet, exercise)
b. Insulin if necessary

Sickle cell disease

Sickle cell disease (SCD), also known as sickle cell anaemia, is a group of inherited blood disorders. This means it's passed down from parents to their children through genes. At its core, SCD affects haemoglobin, the protein in red blood cells responsible for carrying oxygen throughout the body. SCD is caused by a mutation (a change) in the *HBB* gene. This gene provides instructions for making beta-globin, a component of haemoglobin. A specific mutation in the *HBB* gene leads to the production of an abnormal form of haemoglobin called haemoglobin S (HbS).

Normally, healthy red blood cells contain normal haemoglobin (HbA), are round, flexible, and can easily move through even the smallest blood vessels to deliver oxygen. In individuals with SCD, the presence of HbS causes red blood cells to become rigid, sticky, and take on a characteristic "sickle" or C-shape, especially when they release oxygen.

These sickled cells have several problems:

a. They are stiff and sticky: They cannot move easily through small blood vessels and tend to clump together, blocking blood flow.
b. They die prematurely: Sickled cells have a much shorter lifespan (10-20 days) compared to normal red blood cells (100-120 days). This leads to a chronic shortage of red blood cells, a condition called anaemia.

The blockage of blood flow and the chronic anaemia are responsible for the wide range of symptoms and complications associated with SCD, including severe pain episodes (vaso-occlusive crises), organ damage (spleen, kidney, liver, lungs), increased risk of infection, and stroke.

Inheritance Pattern: Autosomal Recessive

Sickle cell disease is inherited in an autosomal recessive pattern. This means that a child will only develop SCD if they inherit two copies of the mutated HBB gene, one copy from each parent.

Normal Gene (HbA): Represents the gene for normal haemoglobin.

Sickle Cell Gene (HbS): Represents the gene for abnormal haemoglobin.

If both parents have Sickle Cell Trait (HbAS)

a. Each parent carries one normal gene (HbA) and one sickle cell gene (HbS). They do not have SCD themselves, but they are "carriers" of the gene.

b. People with sickle cell trait usually do not experience symptoms, except in rare, extreme conditions like severe dehydration or intense physical activity.

For each child they have, there is a;

i. 25% chance (1 in 4) that the child will inherit two normal genes (HbAA) and will not have SCD or be a carrier.

ii. 50% chance (1 in 2) that the child will inherit one normal gene and one sickle cell gene (HbAS), meaning they will also have sickle cell trait and be a carrier.

iii. 25% chance (1 in 4) that the child will inherit two sickle cell genes (HbSS), meaning they will have sickle cell disease.

This is the most common way SCD is inherited.

If one parent has Sickle Cell Disease (HbSS) and the other has Sickle Cell Trait (HbAS)

a. The parent with SCD has two sickle cell genes (HbSS).

b. The parent with sickle cell trait has one normal and one sickle cell gene (HbAS).

For each child they have, there is a;

i. 50% chance (1 in 2) that the child will inherit one HbS gene from the parent with SCD and one HbS gene from the carrier parent, resulting in HbSS (sickle cell disease).

ii. 50% chance (1 in 2) that the child will inherit one HbS gene from the parent with SCD and one HbA gene from the carrier parent, resulting in HbAS (sickle cell trait).

iii. No children will be completely unaffected (HbAA) in this scenario.

If one parent has Sickle Cell Disease (HbSS) and the other has normal haemoglobin (HbAA)

a. The parent with SCD has two sickle cell genes (HbSS).

b. The parent with normal haemoglobin has two normal genes (HbAA).

c. All children (100% chance) will inherit one HbS gene from the affected parent and one HbA gene from the unaffected parent, meaning all their children will have sickle cell trait (HbAS). None will have SCD.

If both parents have normal haemoglobin (HbAA), All children (100% chance) will have normal haemoglobin (HbAA) and will not have SCD or be carriers.

Spinal Muscular Atrophy (SMA)

The term "progressive muscular atrophies" can be broad, but the description provided strongly points to Spinal Muscular Atrophy (SMA) as a key example of a severe, heritable muscle disorder affecting infants. Atrophy refers to the wasting away or decrease in the size of a body part, in this case, muscles, due to a lack of normal development or use. SMA is a group of genetic diseases that affect the motor neurons in the spinal cord. Motor neurons are nerve cells that send signals from the brain and spinal cord to the muscles, controlling muscle movement. In SMA, these motor neurons progressively degenerate and die, leading to muscle weakness and wasting (atrophy). It affects movement

Causes of Spinal Muscular Atrophy (SMA)

a. **Genetic Cause:** SMA is primarily caused by a mutation in the Survival Motor Neuron 1 (SMN1) gene. This gene is responsible for producing the SMN protein, which is crucial for the health and survival of motor neurons. When the SMN1 gene is mutated or missing, insufficient SMN protein is produced, leading to the degeneration of motor neurons.

b. **Inheritance Pattern**: SMA is an autosomal recessive disorder. This means that an individual must inherit two copies of the mutated SMN1 gene (one from each parent) to develop the condition. If a person inherits only one mutated copy, they are a carrier and typically do not show symptoms, but they can pass the gene on to their children.

Albinism

Albinism is another group of recessively inherited genetic disorders that affects the production of melanin, the pigment responsible for the colour of skin, hair, and eyes. It is not contagious and does not inherently affect intelligence or physical health beyond the issues directly related to pigmentation.

Genetic Basis and Types of Albinism

Albinism results from mutations in specific genes that are involved in the production of melanin. There are different types of albinism, classified based on the gene affected and the degree of pigment reduction. The most common type is oculocutaneous albinism (OCA), which affects the skin, hair, and eyes. Ocular albinism (OA) primarily affects the eyes.

a. **Inheritance Pattern:** Most forms of albinism, including the common types of OCA, are inherited in an autosomal recessive pattern. This means that both parents must be carriers of the mutated gene (each having one normal copy and

one mutated copy) for their child to have albinism. If a child inherits two copies of the mutated gene (one from each carrier parent), they will develop albinism.

b. **Melanocytes:** The disorder affects melanocytes, which are specialized cells located primarily in the skin, hair follicles, and eyes. These cells produce melanin. In albinism, either the melanocytes cannot produce melanin at all, or the amount of melanin produced is significantly reduced, or the quality of melanin is altered.

Characteristics and Associated Issues

Individuals with albinism typically exhibit striking physical characteristics due to the lack or reduction of melanin:

a. **Skin Colour**: The skin can appear very pale or strikingly white, sometimes with a pinkish hue due to visible blood vessels. It does not tan and remains abnormally sensitive to sunlight. It may indeed appear wrinkled prematurely due to sun damage.

b. **Hair Colour:** Hair can range from very white to light yellow, light brown, or reddish, depending on the type of albinism and the individual's ethnic background.

c. **Eye Colour**: Eyes can appear very light blue, grey, green, or, less commonly, reddish-pink (due to the visible blood vessels in the iris when pigment is absent).

d. **Vision Problems**: This is a hallmark of albinism and is often the most impactful health concern. Melanin plays a crucial role in the normal development of the optic nerves and retina.

The Test Cross: Determining Unknown Genotypes

Beyond predicting offspring from known parents, Punnett's work (and Mendel's prior insights) also provided a method to determine the genotype of an organism that displays a dominant phenotype but whose underlying genotype is unknown (e.g., is a yellow-seeded pea plant YY or Yy). This method is called the test cross.

Principle: A test cross involves crossing the individual with the unknown dominant phenotype with an individual that is homozygous recessive for the same characteristic. The homozygous recessive individual's genotype (yy) is known, and it will only contribute recessive alleles (y) to its gametes.

Scenario 1: Unknown Dominant Individual is Homozygous Dominant (YY)

Cross: YY (unknown) x yy (test cross parent)

Punnett Square: All offspring will be Yy.

Phenotypes: All F1 offspring will express the dominant trait (e.g., all yellow seeds). This indicates the unknown parent was YY.

Scenario 2: Unknown Dominant Individual is Heterozygous (Yy)

Cross: Yy (unknown) x yy (test cross parent)

Punnett Square: Offspring will be 50% Yy and 50% yy.

Phenotypes: The F1 offspring will exhibit a 1:1 ratio of the dominant phenotype to the recessive phenotype (e.g., 1 yellow seed: 1 green seed). This indicates the unknown parent was Yy.

The test cross is a powerful analytical tool that further supports Mendel's postulate of segregation, as the appearance of recessive offspring directly reveals the presence of a recessive allele in the previously unknown parent. This technique is widely used in plant and animal breeding to ensure desired genetic lines.

Pedigree Analysis: Tracing Inheritance in Humans

While test crosses are valuable in experimental settings, they are unethical and impractical for humans. Instead, geneticists use pedigree analysis to study the inheritance patterns of human genetic diseases and other traits within families.

Organisation and Symbols of a Pedigree

A pedigree is a standardised diagram that represents the ancestral history of a genetic trait within a family.

Generations:

Each horizontal row represents a single generation, with the oldest generation at the top of the pedigree and the most recent generation at the bottom. Generations are typically numbered with Roman numerals (I, II, III...).

Individuals:

Males: Represented by squares (□).

Females: Represented by circles (○).

Affected Individuals: Shaded (or filled) shapes (e.g., blue or black) indicate individuals who express the trait or disease.

Unaffected Individuals: Unshaded (or clear) shapes indicate individuals who do not express the trait.

Carriers: Half-shaded or a dot within the shape can sometimes indicate individuals who are heterozygous carriers for a recessive trait but do not show the phenotype.

Relationships:

Marriage/Mating: A single horizontal line connects individuals who have had children together.

Offspring: Children are connected to their parents' horizontal mating line by a vertical line, typically arranged in birth order from left to right.

Twins: Indicated by two vertical lines diverging from the same point on the parental line. Identical (monozygotic) twins have a horizontal line connecting their two vertical lines.

Analysing Inheritance Patterns with Pedigrees: Geneticists use pedigree analysis to deduce genotypes and predict the likelihood of a trait appearing in future generations. Key patterns emerge:

Recessive Traits: Affected individuals often have unaffected parents (who must be carriers). The trait may skip generations. Affected individuals are usually homozygous recessive (aa).

Example: Alkaptonuria: Individuals with alkaptonuria cannot properly metabolise phenylalanine and tyrosine, leading to symptoms like darkened skin, brown urine, and joint damage. In a pedigree, unaffected individuals (e.g., AA or Aa) might have affected offspring (aa), indicating that both unaffected parents must be heterozygous carriers (Aa). If an individual is unaffected but has an affected sibling, their genotype could be AA or Aa, often represented as A?

Dominant Traits: Affected individuals usually have at least one affected parent. The trait appears in every generation. Affected individuals transmit the trait to approximately half their offspring if heterozygous.

Activity 8.5 Video on Hereditary Disorders

Watch the video linked below.

https://www.youtube.com/watch?v=UC-YwiB_FFg&t=4s

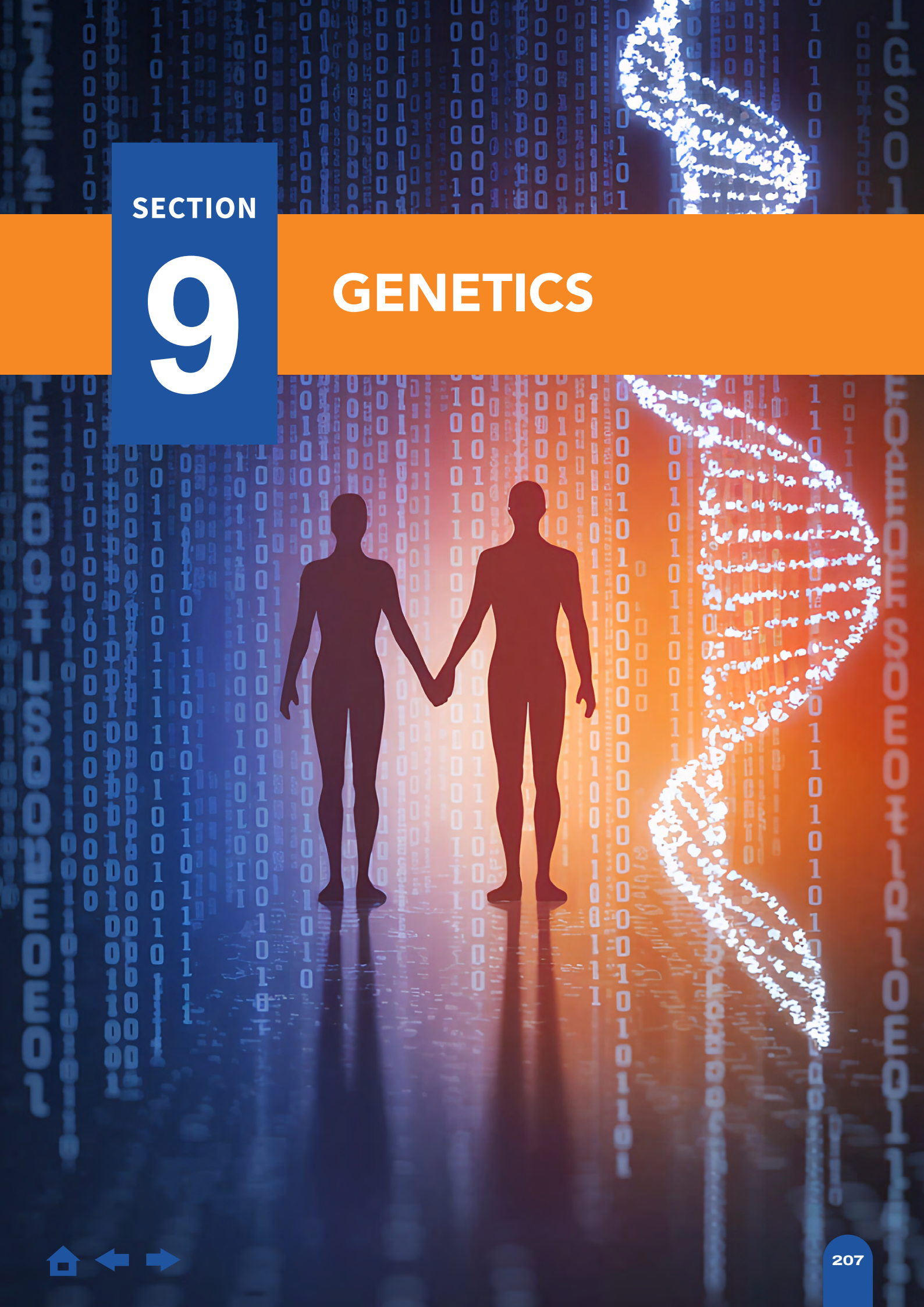
REVIEW QUESTIONS

1. Explain how polygenic inheritance differs from Mendelian inheritance. Use the example of human skin colour to describe how multiple genes can lead to a continuous range of phenotypes.
2. Analyse the relationship between Mendel's Law of Segregation and the Law of Independent Assortment. How do these two laws work together during gamete formation to ensure genetic variation in the F2 generation of a dihybrid cross?
3. Explain why a person with sickle cell trait (HbAS) is considered a carrier and typically does not show severe symptoms of sickle cell disease.
4. Haemophilia is an X-linked recessive disorder. A woman is a carrier, and a man is unaffected. Analyse the genetic risks for their children. Construct a Punnett square to show the possible genotypes and phenotypes of their offspring and explain why the sons and daughters have different probabilities of being affected or being carriers.

SECTION

9

GENETICS



RELATIONSHIPS WITH THE ENVIRONMENT

INTRODUCTION

In this section, we will explore the world of human genetics, where you will learn how your unique traits are passed down from your parents. We will explore the principles of Mendelian genetics to understand how we inherit traits like dimples, tongue rolling, and attached earlobes. We will also cover sex determination and the role of the X and Y chromosomes in deciding if you are male or female.

KEY IDEAS

- **Mendelian Crossings and Sex Determination:** Human sex is determined by the inheritance of sex chromosomes (X and Y) from parents, a process that follows Gregor Mendel's principles of inheritance.
- **Chromosomal Basis of Sex:** Humans have 23 pairs of chromosomes (22 pairs of autosomes and one pair of sex chromosomes. The chromosomal basis of sex in humans depends on the 23rd pair of chromosomes. Females have two X chromosomes (XX), and males have one X and one Y chromosome (XY).
- **Role of the Father's Gamete:** The father's sperm, which can carry either an X or a Y chromosome, determines the sex of the child at the moment of fertilization.
- **Sex-Linked Inheritance:** Genes on sex chromosomes (X or Y) follow different inheritance patterns than genes on autosomes, affecting males and females differently.
- **X-Linked Traits:** Conditions caused by genes on the X chromosome are more common in males. Females with one affected X chromosome are typically **carriers** and often don't show symptoms.
- **Y-Linked Traits:** Genes on the Y chromosome are passed exclusively from a father to all of his sons. Daughters cannot be affected or be carriers.

MENDELIAN CROSSINGS IN HUMAN SEX DETERMINATION

Mendelian crossing is based on the work of Gregor Mendel, who discovered how traits are passed from parents to their children through genes. One example of this in humans is how biological sex (male or female) is determined.

Humans have 23 pairs of chromosomes in each cell. One of these pairs is called the **sex chromosomes.** Females have two X chromosomes **(XX),** while males have one X and one Y chromosome **(XY).**

When a baby is made; the mother always passes on an X chromosome. The father can pass on either an X or a Y:

a. If the father gives an X → the baby is **female (XX)**
b. If the father gives a Y → the baby is **male (XY)**

This follows **Mendel's law of segregation**, which says that each parent passes on only one of their two chromosomes to their child. So, the sex of the baby depends on which sex chromosome the father passes on to him or her.

Genetic Control of Sex Determination

In higher organisms like humans, a person's sex is usually determined at the moment of fertilization. This is because of special chromosomes called **sex chromosomes**, which carry genes that control how sexual characteristics develop. Some animals, such as certain fish, use different genes on **autosomes** (non-sex chromosomes) to decide sex. However, in most complex organisms, the most common and well-understood way sex is determined is through **chromosomal sex determination**.

The XX-XY System in Humans

Humans have 23 pairs of chromosomes, making a total of 46 chromosomes in each body (somatic) cell. Out of these, 22 pairs are called **autosomes.** These chromosomes carry genes for most of the body's traits and are the same in both males and females. The remaining one pair is called the **sex chromosomes**, which determine a person's biological sex.

a. **Females** have two X chromosomes (**XX**)
b. **Males** have one X and one Y chromosome (XY)

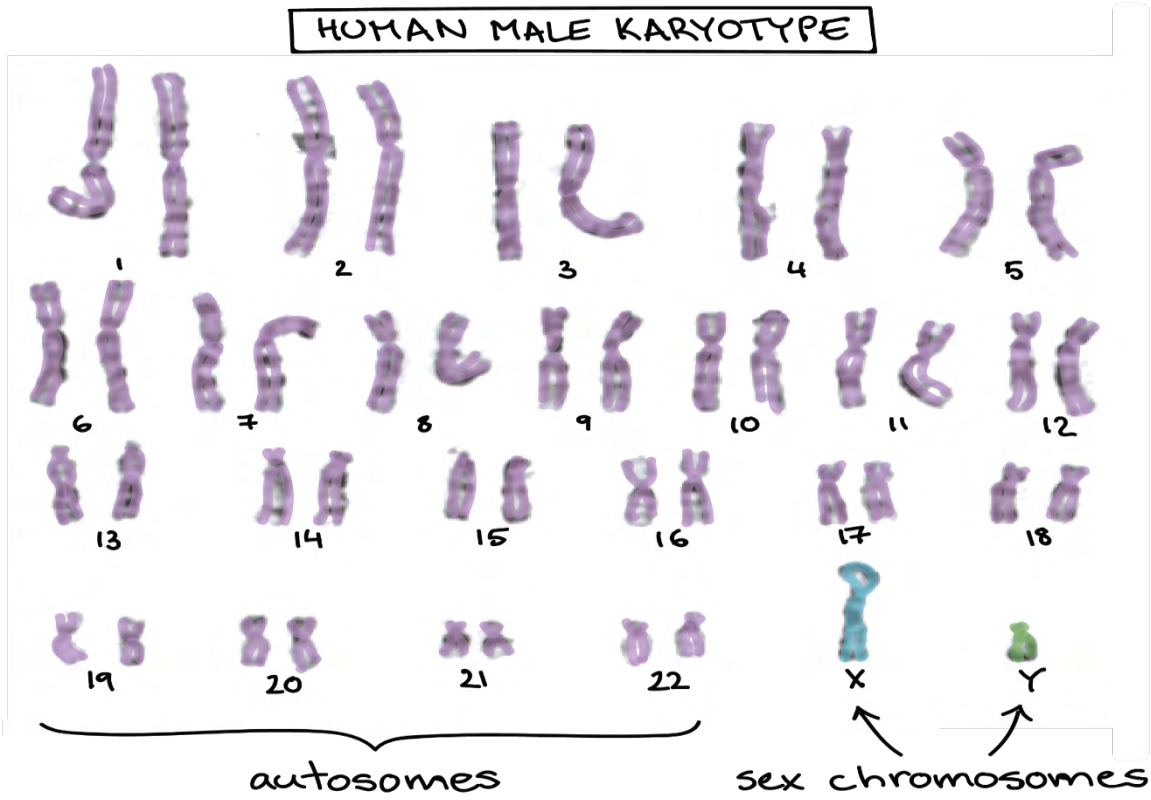


Figure 9.1: Pairs of chromosomes

Humans and many other mammals use the **XX-XY system** to determine sex:

a. **Females** have two **X chromosomes → XX**
b. **Males** have one **X chromosome** and one **Y chromosome → XY**

What Happens During Fertilisation?

Sex is determined at the moment of **fertilisation**, when a sperm cell from the father joins with an egg cell from the mother.

Egg cells (from the mother) **always carry an X chromosome**, because females are XX.

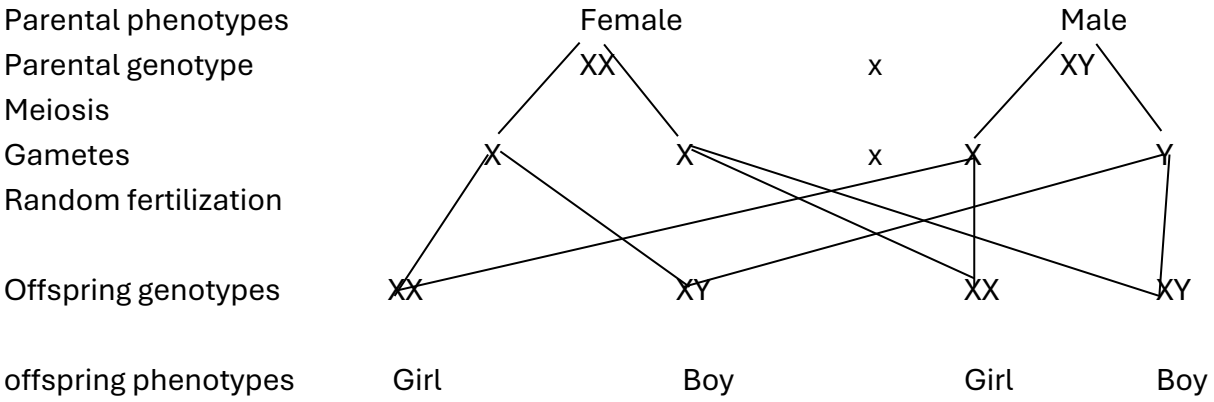
Sperm cells (from the father) can carry **either an X or a Y chromosome**, because males are XY.

This means:

a. If a **sperm with an X chromosome** fertilizes the egg (which has an X), the baby will be **XX → female.**
b. If a **sperm with a Y chromosome** fertilizes the egg, the baby will be **XY → male**.

So, the **father's sperm determines the sex of the child.**

There is about a **50% chance** of having a boy and a **50% chance** of having a girl in each pregnancy.This scientific explanation proves that the **mother does not control** the sex of the baby; a belief that was wrongly accepted in the past.



Other Types of Sex Determination Systems

While the XX-XY system is common, other mechanisms exist:

1. **ZW-ZZ System:** Found in birds, some fish, and some insects (e.g., butterflies). In this system, females are the heterogametic sex (ZW) and males are homogametic (ZZ).
2. **XO System:** Seen in many insects (e.g., grasshoppers). Females are XX, but males have only one X chromosome (XO), lacking a Y chromosome.
3. **Haplodiploidy System:** Characteristic of social insects like bees, ants, and wasps. Males develop from unfertilized eggs (haploid, having one set of chromosomes), while females develop from fertilized eggs (diploid, having two sets of chromosomes).
4. **Environmental Sex Determination:** In some reptiles (e.g., crocodiles, turtles), the temperature during egg incubation determines the sex of the offspring.

Sex-Linked Inheritance: Genes on Sex Chromosomes

Sex linkage refers to the inheritance patterns of genes located specifically on the sex chromosomes (X or Y), rather than on the autosomes. These genes are called sex-linked genes or X-linked/Y-linked genes, and their inheritance patterns differ significantly from autosomal traits because males and females have different numbers of X and Y chromosomes.

X-Linked Inheritance

The **X chromosome** is much larger than the Y chromosome and contains a significantly greater number of genes (over 900 genes). Genes found on the X chromosome can affect both males and females. X-linked traits can be either recessive or dominant.

X-Linked Recessive Inheritance

1. **Common in Males:** X-linked recessive conditions are much more prevalent in males than in females. This is because males have only one X chromosome. If a male inherits a mutated recessive allele on his X chromosome, he will express the trait because he has no second X chromosome to provide a normal, dominant allele to mask it.
2. **Females as Carriers:** Females have two X chromosomes. If a female inherits one mutated recessive allele on one X chromosome and a normal, dominant allele on the other X chromosome, she will usually be a carrier. She typically won't show symptoms herself (or may have milder symptoms due to skewed X-inactivation, where one of the X chromosomes is preferentially inactivated), but she can pass the mutated allele to her children.

Inheritance Patterns

1. **Affected Son from a Carrier Mother:** A son born to a carrier mother and an unaffected father has a 50% chance of inheriting the mutated and thus being affected.
2. **Daughters of Carrier Mothers**: Daughters of a carrier mother have a 50% chance of being carriers themselves. They rarely show the full condition unless they inherit the recessive allele from both parents (which is rare, requiring an affected father and a carrier/affected mother) or exhibit skewed X-inactivation.
3. **Affected Father:** An affected father cannot pass the X-linked trait to his sons (as sons inherit the Y chromosome from their father). However, all his daughters will be carriers because they inherit his X chromosome.

Examples of X-linked recessive conditions include

1. **Red-green colour blindness**: Difficulty distinguishing between shades of red and green.
2. **Haemophilia A and B**: Blood-clotting disorders where the blood does not clot properly.
3. **Duchenne Muscular Dystrophy**: A progressive muscle-wasting disease. It manifests very early in childhood causing delayed walking and difficulty in running
4. **Glucose-6-phosphate dehydrogenase (G6PD) deficiency:** A disorder where the body lacks enough of an enzyme needed for th survival of red blood cells. This condition can lead to haemolytic anaemia, often triggered by certain foods, drugs, or infections.

Example: Inheritance of Haemophilia

Let's use the Punnett square you provided to illustrate haemophilia inheritance: (XH = normal allele, Xh = haemophilia allele)

X	X^H	X^h
X^H	$X^H X^H$	$X^H X^h$
Y	$X^H Y$	$X^h Y$

This Punnett square shows that if the mother is a carrier and the father is unaffected:

1. There's a 50% chance for daughters to be carriers and a 50% chance to be unaffected.
2. There's a 50% chance for sons to be affected and a 50% chance to be unaffected. This explains why it primarily affects males.

X-Linked Dominant Inheritance

1. **Rare:** X-linked dominant conditions are less common than X-linked recessive ones.

2. **Inheritance Patterns:**
   a. **Affected Mother:** If an affected mother has children with an unaffected father, there is a 50% chance for both sons and daughters to be affected. However, some X-linked dominant conditions can be lethal to male embryos, making them appear almost exclusively in females.
   b. **Affected Father:** If an affected father has children with an unaffected mother, all his daughters will be affected because they inherit his X chromosome. None of his sons will be affected, as they inherit his Y chromosome.

Examples of X-linked dominant conditions include

1. **Rett syndrome**: A severe neurodevelopmental disorder (often lethal in males).
2. **Fragile X syndrome (in some cases)**: While primarily X-linked recessive, some female carriers can show milder symptoms due to X-inactivation. It causes intellectual disability.
3. **Vitamin D-resistant rickets** (X-linked hypophosphatemia). This genetic disorder causing chronic severe bone softening, bow legs and some dental issues.

Y-Linked Inheritance (Holandric Inheritance)

Y-linked traits, also known as holandric traits, are determined by genes located exclusively on the Y chromosome. The Y chromosome is much smaller than the X chromosome and contains very few genes (estimated around 200).

1. **Inheritance Pattern:** Y-linked conditions are passed only from father to son and will affect all sons of an affected father. Daughters will never be affected and cannot be carriers, as they do not inherit a Y chromosome.
2. **Limited Recombination:** The Y chromosome generally does not undergo genetic recombination (crossing over) with other chromosomes, except for small regions called pseudo autosomal regions. This means that Y-linked genes are typically passed down unchanged from father to son through generations.
3. **Difficulty in Detection:** Due to the Y chromosome's small size and limited gene content, Y-linked traits were historically difficult to confirm. However, advancements in DNA sequencing have allowed for more accurate identification of Y-linked genes.
4. **Examples:** Most well-established Y-linked genes are involved in male sex determination and fertility. A common example is the SRY gene (Sex-determining Region Y gene), which triggers male development. Other Y-linked genes are associated with conditions like certain forms of male infertility due to Y-chromosome deletions.

5. **Hypertrichosis pinnae auris (hairy ears):** Was once thought to be a Y-linked trait but later discredited. This highlights the challenges in definitively confirming Y-linkage without modern genetic tools.

Characteristics of Y-linked inheritance

1. Occurs only in males.
2. Appears in all sons of males who exhibit the trait.
3. Is absent from daughters of trait carriers.

Other Complex Inheritance Patterns

Beyond simple Mendelian inheritance and sex-linked patterns, many traits are influenced by multiple genes and environmental factors:

a. **Sex-Influenced Traits:** Sex-influenced traits are autosomal traits whose expression or dominance is influenced by an individual's biological sex. This means an allele might be dominant in one sex but recessive in the other, often due to differences in sex hormones.

Example: Pattern Baldness in Humans: The gene for pattern baldness is located on an autosome. It acts as a dominant trait in males (requiring only one copy of the allele for expression) but a recessive trait in females (requiring two copies for significant expression, and even then, expression may be less severe than in males). This is influenced by the presence of male hormones like testosterone.

b. **Sex-Limited Traits:** Sex-limited traits are autosomal traits that are expressed in only one of the sexes, even though the genes for these traits are present in both males and females. The expression is effectively "limited" by the presence or absence of specific sex hormones or anatomical structures.

   Example: Milk Production in Mammals: Genes for milk production are present in both male and female mammals. However, only females express the trait of lactation, as it's dependent on female hormones and mammary gland development.

   Other Examples: Age of onset of menstruation, width of pelvis, and specific patterns of body hair distribution.

c. **Polygenic Inheritance (Multifactorial Traits):** Polygenic inheritance describes traits that are determined by the cumulative effects of multiple genes (alleles at many loci) rather than a single gene. These traits often show continuous variation within a population, meaning there's a gradual range of phenotypes rather than distinct categories.

d. **Continuous Traits:** Unlike "discontinuous traits" (like blood types A, B, O, AB, which fall into clear categories), polygenic traits are "continuous." You can't easily put individuals into distinct groups.

e. **Additive Effect:** In polygenic inheritance, the effect of individual alleles is often small, and they typically do not display simple dominance or recessiveness. Instead, each "contributing allele" adds a small, additive effect to the phenotype.

f. **Multifactorial Traits:** Many polygenic traits are also multifactorial, meaning they are influenced by both multiple genes and environmental factors. Environmental factors can significantly modify the expression of these genetic predispositions.

Examples of Polygenic Inheritance

1. **Skin Colour:** Human skin colour is primarily determined by at least three, and likely more, genes that control the production of melanin. Individuals inherit a combination of "contributing" alleles (leading to darker skin) and "non-contributing" alleles (leading to lighter skin). The additive effect of these alleles results in the wide spectrum of human skin tones.
2. **Human Height:** Height is an incredibly complex multifactorial trait controlled by over 400 genes. This complexity makes predicting an offspring's height challenging. Environmental factors during growth, such as nutrition, health, and exposure to disease, also play a significant role in determining final adult height. Two short parents can have a tall child, and vice versa, due to the complex interplay of numerous genes and environmental influences.
3. **Weight, Body Build, Intelligence:** These are also examples of complex multifactorial traits influenced by many genes and environmental factors.

FOCAL AREA: UNDERSTANDING MENDELIAN INHERITANCE THROUGH HUMAN TRAITS

Have you ever wondered why you have your mother's eyes or your father's nose? Or why some siblings look so similar while others appear quite different? The answers lie in the fascinating field of genetics, the study of heredity, which is how traits are passed from parents to their offspring.

As you have already learnt, centuries ago, a curious monk named Gregor Mendel conducted groundbreaking experiments with pea plants. His meticulous work, long before the discovery of DNA, laid the foundation for our understanding of how traits are inherited. His principles, now known as Mendelian genetics, provide a powerful framework for predicting the patterns of inheritance for many simple traits.

This week, we will dive into selected human traits that often follow Mendelian patterns of inheritance. You will continue to learn to use the tools of Mendelian crossing, like the Punnett Square, to predict the likelihood of offspring inheriting specific characteristics. By observing traits in yourselves, your families, and even your classmates, you'll gain a deeper appreciation for the genetic blueprint that makes each of us unique.

KEY IDEAS

- Explanation of polygenic inheritance.
- Prediction of inherited traits.
- The meaning of genotype and phenotype.
- What sex-inked traits are.

SELECTED MENDELIAN HUMAN TRAITS

Many human traits are complex and influenced by multiple genes and environmental factors (polygenic or multifactorial traits). However, some fascinating traits are widely accepted to follow simple Mendelian inheritance patterns, making them excellent examples for our study. Some common examples are:

1. **Earlobe attachment**
   a. **Phenotypes:** Free earlobes versus attached earlobes.
   b. **Inheritance pattern:** Free earlobes are generally considered dominant over attached earlobes.
   c. **Alleles:** Allele for free earlobes, F, is dominant while allele for attached earlobes, f, is recessive.

2. **Genotypes and phenotypes**
   a. **FF**: Free earlobes (homozygous dominant)
   b. **Ff**: Free earlobes (heterozygous)
   c. **ff**: Attached earlobes (homozygous recessive)

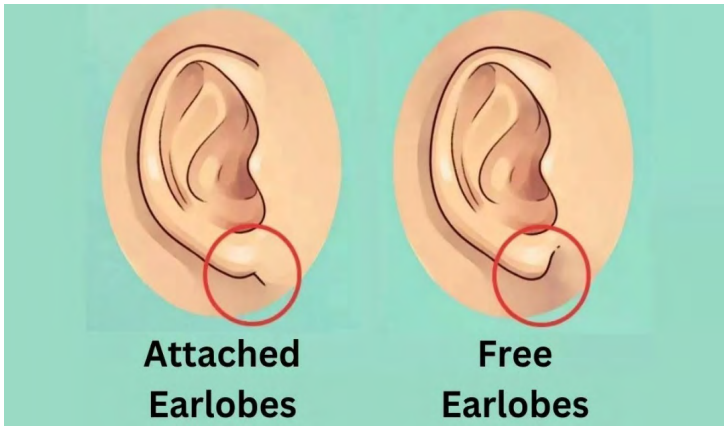


Figure 9.2: Attached ear lobe (left), free ear lobe (right)

3. **Widow's peak hairline**
   a. **Phenotypes:** Widow's peak (V-shaped hairline) versus straight hairline.

b. **Inheritance pattern:** Widow's peak is generally considered dominant over a straight hairline.

c. **Alleles**

i. W: Allele for Widow's peak (dominant).

ii. w: Allele for straight hairline (recessive).

d. **Genotypes and phenotypes**

i. WW: Widow's peak (homozygous dominant).

ii. Ww: Widow's peak (heterozygous).

iii. ww: Straight hairline (homozygous recessive).

4. **Tongue rolling**

a. **Phenotypes:** Ability to roll tongue into a U-shape versus inability to roll tongue.

b. **Inheritance pattern:** Tongue rolling is generally considered dominant over non-rolling.

c. **Alleles**

i. R: Allele for tongue rolling (dominant).

ii. r: Allele for non-rolling (recessive).

d. **Genotypes and phenotypes**

i. RR**:** Tongue Rolling (homozygous dominant)

ii. Rr: Tongue Rolling (heterozygous)

iii. rr: Non-rolling (homozygous recessive).

5. **Dimples**

a. **Phenotypes:** Presence of dimples versus absence of dimples.

b. **Inheritance pattern:** Presence of dimples is generally considered dominant over the absence of dimples.

c. **Alleles**

i. D: Allele for Dimples (dominant).

ii. d: Allele for No Dimples (recessive).

d. **Genotypes and phenotypes**

i. DD: Dimples (homozygous dominant).

ii. Dd: Dimples (heterozygous).

iii. dd: No dimples (homozygous recessive).

6. **Phenylthiocarbamide (PTC) tasting**

a. **Phenotypes:** Ability to taste PTC versus inability to taste PTC

b. **Inheritance pattern:** Ability to taste PTC is generally considered dominant over non-tasting. (PTC is a harmless chemical often found on special paper strips used for testing).

c. **Alleles**

   i. T: Allele for PTC taster (dominant).

   ii. t: Allele for PTC non-taster (recessive).

d. **Genotypes and phenotypes:**

   i. TT: PTC Taster (homozygous dominant).

   ii. ii Tt: PTC Taster (heterozygous).

   iii. tt: PTC Non-taster (homozygous recessive).

The Punnett Square

This is a simple yet powerful tool for visualizing and predicting the outcomes of genetic crosses.

Steps for performing a monohybrid cross using the example of earlobe attachment:

Scenario: A man who is heterozygous for free earlobes (Ff) marries a woman who is also heterozygous for free earlobes (Ff). What are the possible genotypes and phenotypes of their children, and what are the probabilities?

Step 1: Identify the trait and its alleles

a. Trait: Earlobe attachment.

b. Alleles: F (Free earlobes - dominant), f (Attached earlobes - recessive)

Step 2: Determine the genotypes of the parents (P generation)

a. Man's genotype: Ff

b. Woman's genotype: Ff

Step 3: Determine the possible gametes each parent can produce

Each parent, being heterozygous (Ff), can produce two types of gametes: one carrying the F allele and one carrying the f allele.

a. Man's gametes: F, f

b. Woman's gametes: F, f

Step 4: Draw a Punnett Square and fill it in

a. Place the possible gametes from one parent along the top row.

b. Place the possible gametes from the other parent along the left column.

c. Fill in each box by combining the alleles from the corresponding row and column.

Gametes (X)	F	f
F	FF	Ff
f	fF	ff

Step 5: Determine the predicted genotypes and phenotypes of the offspring (First filial generation, F1) and their ratios/probabilities.

a. Genotypes

i. FF: 1 out of 4 squares (1/4 or 25%)

ii. Ff: 2 out of 4 squares (2/4 or 1/2 or 50%)

iii. ff: 1 out of 4 squares (1/4 or 25%)

iv. Genotypic Ratio: 1 FF: 2 Ff: 1 ff

b. Phenotypes

i. Free earlobes (FF and Ff): 3 out of 4 squares (3/4 or 75%)

ii. Attached earlobes (ff): 1 out of 4 squares (1/4 or 25%)

c. Phenotypic ratio: 3 Free earlobes: 1 attached earlobes

Activity 9.1 My family's genetic traits

Aim: To use Mendelian genetics to verify observable traits in oneself and one's family.

Important ethical note

a. This activity is for educational purposes only.

b. Do not attempt to diagnose any medical conditions or make judgments about individuals based on these simple traits.

c. Always ask for permission before observing or discussing traits with family members, and respect their privacy.

What you need

- Pen/Pencil
- This reference material
- Observation skills
- Optional: PTC taste strips (if available for testing PTC tasting)

What to do

a. Observe your own traits: For each trait listed in the table below, determine your own phenotype.

b. Observe your family traits: With permission, observe the same traits in your parents and siblings. If you don't know or cannot observe a trait for a family member, leave it blank.

Fill in the Table: Record your observations in the "Phenotype" column

Trait	Dominant phenotype	Recessive phenotype	My phenotype (circle one)	Parent 1 phenotype	Parent 2 phenotype	Sibling 1 phenotype	Sibling 2 phenotype
Earlobe attachment	Free	Attached	Free/ attached				
Widow's peak	Widow's peak	Straight hairline	Widow's peak/ Straight hairline				
Tongue rolling	Can roll tongue	Cannot roll tongue	Can roll/ cannot roll				
Dimples	Present	Absent	Present/ Absent				
PTC tasting	Can taste	Cannot taste	Can taste/ cannot taste				

Analysis

Using the information from week 14 and week 16, answer the following questions. If you need to make assumptions about genotypes (e.g., if a parent has a dominant phenotype but their genotype isn't known from observations), state your assumptions clearly.

a. **Your genotypes:** Based on your phenotype and your parents' phenotypes, try to determine your most likely genotype for each trait. Explain your reasoning.

b. Example: If you have attached earlobes (ff), both your parents must carry the 'f' allele. If they both have free earlobes, they must both be heterozygous (Ff).

c. **Parental genotypes:** For any trait where you and your parents have a dominant phenotype but an offspring has a recessive phenotype (e.g., parents both have free earlobes, but a sibling has attached ones), what must the parents' genotypes be? Show a Punnett Square to support your answer.

d. **Predicting offspring:** If two individuals, both heterozygous for tongue rolling (Rr x Rr), were to have children, what is the probability that their child would *not* be able to roll their tongue? Show your Punnett Square.

e. **Class data (Optional):** If your teacher facilitates, collect class data for each trait and discuss the observed frequencies versus the Mendelian ratios (e.g., why might the 3:1 ratio not be perfectly observed in a small sample like your class?).

Explanation of related terms

While Mendelian crosses are powerful for understanding basic inheritance, it's important to remember that human genetics is often more complex.

1. **Polygenic traits:** Many human traits (like height, skin colour, and intelligence) are influenced by multiple genes acting together, not just one.
2. **Environmental Influences:** The environment can also play a significant role in how genes are expressed (e.g., nutrition affecting height potential).
3. **Incomplete Dominance:** In some cases, the heterozygous phenotype is an intermediate blend of the two homozygous phenotypes (e.g., red and white flowers producing pink offspring).
4. **Codominance:** Both alleles are fully expressed in the heterozygous phenotype (e.g., ABO blood groups, where A and B alleles are codominant).
5. **Sex-linked traits:** Traits determined by genes located on the sex chromosomes (X or Y), leading to different inheritance patterns in males and females (e.g., colour blindness, haemophilia, baldness).

Sample determination of polygenic and sex-linked traits

1. Height (tall/dominant versus short/recessive) trait

Assumption: Tall (T) is dominant and short (t) is recessive.

A heterozygous tall person (Tt) is crossed with another heterozygous tall person (Tt).

Punnett Square

Gametes (X)	T	t
T	TT	Tt
t	Tt	tt

Genotypes: 1 TT (homozygous dominant), 2 Tt (heterozygous), 1 tt (homozygous recessive).

Genotypic ratio: 1TT (25%) : 2Tt (50%) : 1tt (25%)

Phenotypes: 3 out of 4 offsprings are tall while 1 out of 4 is short.

Interpretation

There is a 75% chance of a tall child and 25% chance of a short child.

Now, let us explain height as polygenic inheritance using Punnet Square.

Assume 2 gene pairs, each with a dominant and recessive allele:

Thus, let **A = tall**, **a = short**,

B = tall, **b = short.**

Each dominant allele contributes to tallness. The more the dominant alleles, the taller is the individual.

Parent Genotypes: Aa Bb × Aa Bb

We will create a 16-square Punnett Square using all combinations.

Step 1: Possible gametes from each parent are as follows:

Gametes of parent AaBb: AB, Ab, aB, ab

Step 2: Punnett Square

Gametes	AB	Ab	aB	ab
AB	AABB	AABb	AaBB	AaBb
Ab	AABb	AAbb	AaBb	Aabb
aB	AaBB	AaBb	aaBB	aaBb
ab	AaBb	Aabb	aaBb	aabb

Count dominant alleles and interpret phenotype. This is tabulated as follows:

Genotype	Dominant alleles	Phenotype
AABB	4	Very tall
AABb	3	Tall
AaBB	3	Tall
AaBb	2	Medium height
AAbb	2	Medium height
Aabb	1	Short
aaBB	2	Medium height
aaBb	1	Short
aabb	0	Very short

2. Skin colour

A simplified model using one gene pair.

Note: In reality, skin colour is a polygenic trait influenced by multiple genes. But for teaching Mendelian basics, a simplified dominant/recessive model is used.

Assumption: Dark skin (D) is dominant, light skin (d) is recessive.

At crossing: Heterozygous parents Dd × Dd

Punnett Square

Gametes	D	d
D	DD	Dd
d	Dd	dd

Genotypes:1 DD (homozygous dark), 2 Dd (heterozygous dark), 1 dd (homozygous light).

Genotypic ratio: 1DD (25%) : 2Dd (50%) : 1dd (25%)

Phenotypes: 3 dark-skinned, 1 light-skinned

Interpretation: Dark skin appears more frequently due to dominant allele.

Skin colour can be explained as a polygenic inheritance using Punnett Squares as follows:

We will make the following assumptions:

a. Two genes, A and B, control skin pigment.
b. Dominant alleles, A and B, contribute to dark pigment.
c. Recessive alleles, a and b, contribute to light pigment.
d. The total number of dominant alleles determines skin shade.

Parental Genotypes: AaBb × AaBb

Each parent can pass on four possible gametes, AB, Ab, aB, ab

Using a 16-Square Punnett grid:

Gametes	AB	Ab	aB	ab
AB	AABB	AABb	AaBB	AaBb
Ab	AABb	AAbb	AaBb	Aabb
aB	AaBB	AaBb	aaBB	aaBb
ab	AaBb	Aabb	aaBb	aabb

A table of dominant allele count and phenotype is as follows:

Genotype	Dominant alleles	Skin colour phenotype
AABB	4	Very dark
AABb	3	Dark
AaBB	3	Dark
AaBb	2	Medium tone
AAbb	2	Medium tone
aaBB	2	Medium tone
Aabb	1	Light
aaBb	1	Light
aabb	0	Very light

Interpretation:

a. Skin colour shows a range, not just light or dark.
b. Most offsprings are expected to fall into the medium tone category (2 dominant alleles).
c. More dominant alleles yield more melanin which produces a darker skin.

3. Predicting baldness, a sex-influenced trait

a. **Assumption**: Baldness is dominant in males (B), recessive in females (b).
b. **Genotypes:**

i. BB = bald in both sexes.
ii. Bb = bald in males, not bald in females.
iii. bb = not bald in both sexes.

Example: A heterozygous bald man (Bb) marries a heterozygous woman (Bb).

Punnett Square

Gametes	B	b
B	BB	Bb
b	Bb	bb

Genotypes:1 BB: 2 Bb: 1 bb

Phenotypes

a. **Males**

i. BB and Bb = Bald (3 out of 4)

ii. bb = Not bald (1 out of 4)

b. **Females**:

i. BB = Bald (1 out of 4)
ii. Bb = Not bald (2 out of 4)
iii. bb = Not bald (1 out of 4)

Interpretation: This shows how the same genotype (Bb) expresses differently in males and females, due to influence of sex hormones.

Explanation of haemophilia using a Punnett Square

Haemophilia is a sex-linked recessive genetic disorder, most commonly carried on the X chromosome. It affects blood clotting and occurs more frequently in males because they have only one X chromosome (XY), while females have two (XX).

Key points

1. The haemophilia gene is represented by X^h (affected) and a normal X by X.
2. Since males inherit only one X from their mother, if that X carries the haemophilia gene, they will have the disorder.
3. Females need two copies of the haemophilia gene to be affected (X^hX^h), which is rare. If they have one affected X (X^hX), they are carriers.

Punnett Square

Let's consider a **carrier mother (X^hX)** and a normal father (XY).

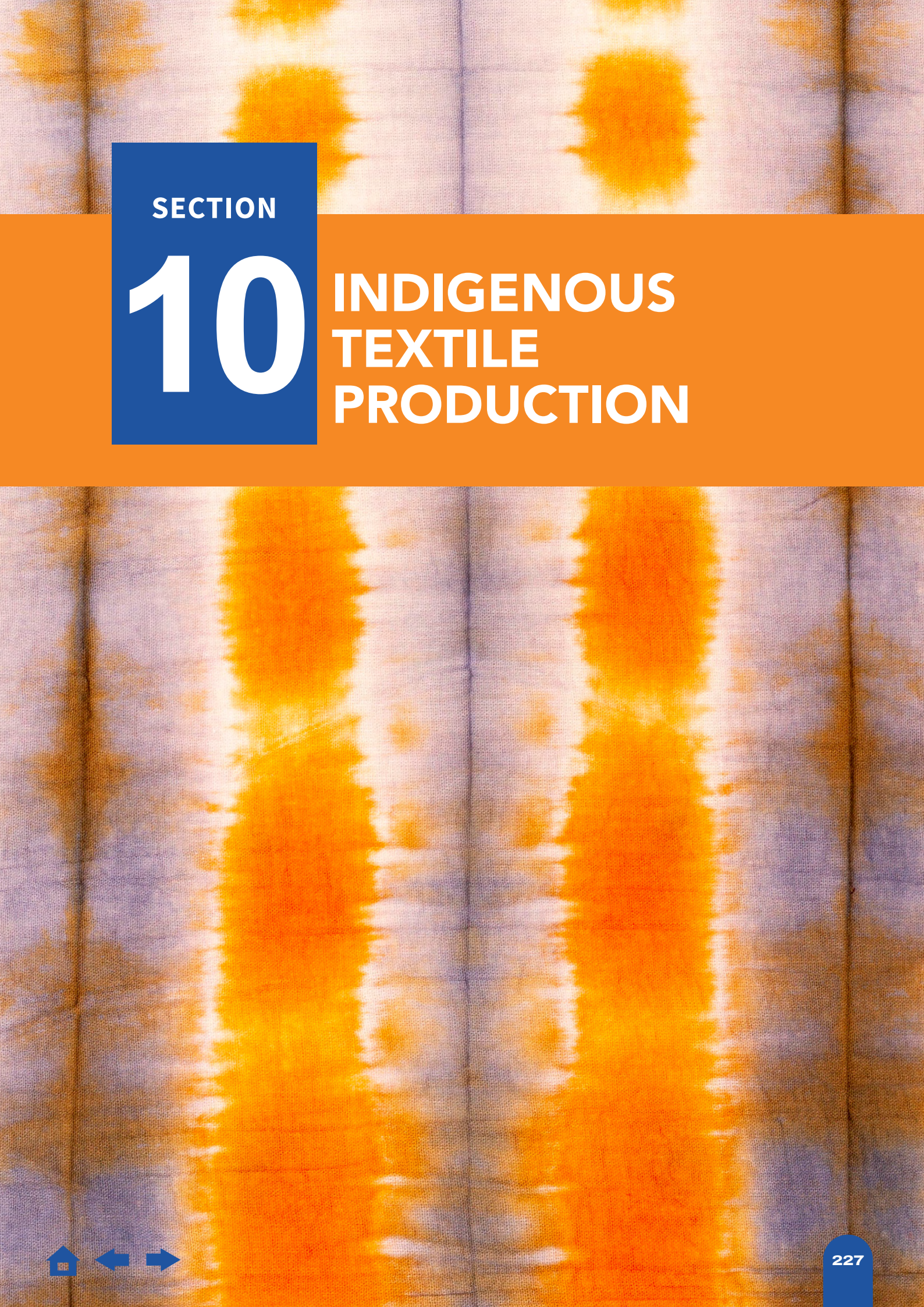
Gametes	**X (father)**	**Y (father)**
X (mother)	XX	XY
X^h (mother)	X^hX	X^hY

Offspring outcomes

1. XX (normal girl) – not affected
2. X^hX (carrier girl) – not affected, but carries the gene
3. XY (normal boy) – not affected
4. X^hY (haemophilic boy) – affected

REVIEW QUESTIONS

1. Describe the inheritance pattern for an X-linked dominant trait and explain why all daughters of an affected father will also be affected.
2. A man has a family history of a Y-linked trait. His wife is unaffected. Analyse the probability that their son will inherit the trait and explain the reasoning behind your conclusion.
3. A man with a straight hairline (ww) and a woman with a Widow's peak (Ww) have children. Use a Punnett Square to predict the percentage of their children who will have a Widow's peak.
4. Analyse a scenario where two parents both have normal hair, but one of their children is bald. Use a Punnett Square to determine the likely genotypes of the parents and explain how the trait of baldness is inherited.



SECTION

10 INDIGENOUS TEXTILE PRODUCTION

RELATIONSHIPS WITH THE ENVIRONMENT

The Science Involved in the Production of Indigenous Textiles

INTRODUCTION

In this section, we will discover the attractive science behind traditional textile production, such as tie-dye, batik, and Adire. These methods use a technique called resist dyeing, where certain parts of the fabric are protected from the dye using materials like wax, strings, or starch to create beautiful patterns. We will investigate the scientific principles at play, including how dye moves into fabric through processes like absorption and diffusion, how materials dissolve (solubility), and how colours are made permanent through chemical fixation. By understanding the role of heat and different types of dyes and fixatives, you will discover how these traditional art forms are deeply rooted in scientific principles.

KEY IDEAS

- **Resist Dyeing Techniques:** Adire, batik, and tie-dye use *resist dyeing*, where parts of fabric are covered with wax, string, or starch to block dye. When removed, they reveal patterned designs that reflect both creativity and an understanding of dye behaviour.
- **Absorption and Diffusion:** Dye spreads through *diffusion*, moving from concentrated areas into fabric fibres. The fabric's *absorption* depends on fibre type—natural fibres like cotton absorb dyes better than synthetics.
- **Solubility and Dye Preparation:** Dyes must fully *dissolve* in water for even colouring. Temperature, pH, and dye composition affect *solubility* and ensure smooth, lasting colour penetration.
- **Chemical Fixation:** *Mordants* or *fixatives* such as alum or soda ash bond dye molecules to fibres, making colours permanent and resistant to fading or washing.
- **Role of Heat:** *Heat* increases molecular movement, helping dyes bond faster and more evenly. In batik, hot wax controls dye spread and sets colour effectively.
- **Eco-Relationships and Sustainability:** Using *natural dyes* from plants, bark, and minerals reflects environmental awareness. These eco-friendly methods reduce pollution and support sustainable resource use.
- **Integration of Art and Science:** Indigenous textile making blends *artistic skill* with *scientific principles*. Through observation and practice, artisans apply chemistry and physics to create durable, beautiful fabrics.

THE SCIENTIFIC PROCESSES INVOLVED IN INDIGENOUS TEXTILES PRODUCTION (SUCH AS TIE-DYE, BATIK, AND ADIRE)

Textile design, far beyond mere aesthetics, profoundly impacts the social, cultural, and economic well-being of individuals, communities, and nations. As a form of mobile cultural heritage, textiles serve as vital storehouses of identity, history, and belief systems, making their preservation, documentation, and study for future generations, research, and public education an imperative.

Defining Indigenous Ghanaian Textiles

In Ghana, indigenous textiles are more than just clothing; they are deeply woven into the fabric of society, representing the attire specific to various ethnic groups with strong historical and cultural roots. While elements like colour palettes, forms, and the yarns and fibre types used may have undergone some modifications across successive generations, the foundational ideas, underlying philosophies, intricate techniques, and rich histories embedded within these textiles have largely remained consistent.

Ghana is a vibrant hub for traditional African fabrics, showcasing a remarkable diversity of indigenous textiles. Examples of textiles found in Ghana include:

1. **Bogolanfini**: Hailing from Mali, its mud-dyed patterns reflect natural earth tones and abstract designs.
2. **Adinkra cloth**: A renowned Ghanaian fabric characterised by its stamped symbols, each carrying deep philosophical meanings and proverbs.
3. **Kuba cloth:** Originally from the Democratic Republic of Congo, known for its intricate geometric patterns created from raffia fibre.
4. **Adire:** A Yoruba resist-dyed textile from Nigeria, employing techniques like tying, stitching, or starch resist.
5. **Kente:** Perhaps the most iconic Ghanaian textile, woven from silk and cotton strips in vibrant, complex geometric patterns, each with specific names and meanings.
6. **Akwete Cloth**: A hand-woven fabric from Nigeria, similar to Kente, known for its bold patterns and vibrant colours.
7. Aso-Oke: A hand-loomed cloth from the Yoruba people of Nigeria, often used for special occasions.

These exquisite textiles are traditionally crafted from natural fibres like cotton, silk, and raffia, and dyed with pigments derived from plants, minerals, or insects. However, a critical challenge lies in their inherent susceptibility to degradation; the natural colours tend to fade over time, making these precious artefacts vulnerable to extinction if not actively preserved.

Indigenous textiles are far more than just handicrafts; they are living cultural artefacts that embody the very history, philosophies, and beliefs of a people. Their intricate designs, chosen colours, and production techniques symbolise a rich cultural history that must be safeguarded to uphold fundamental feelings of self, community, and belonging.

Groups of Indigenous Ghanaian Textiles

1. Traditional textiles made by hand (Kente)

The complete history of kente cloth, one of Ghana's most iconic textiles, is not definitively settled, with various accounts combining legend and historical evidence. Asante mythology attributes the origin of kente weaving to Ota Kraban and Ameyaw in Bonwire, who reputedly drew inspiration from a spider's web, a narrative supported by the prevalence of woven lace and needlework during that era. However, historical accounts often trace kente's roots to ancient weaving traditions in prosperous West African Kingdoms, flourishing between 300 and 1600 AD, pointing to archaeological findings of narrow-strip cloths from Mali, dating back to the 11th century AD.

Regardless of its exact genesis, weaving appears to have been established in West Africa long before the formal creation of kente as we know it. Evidence of early weaving, such as spindle whorls and loom weights, has been found in ancient empires like Meroe (500 BC to 300 AD). In Ghana, weaving reportedly began in the northern regions, initially using rough raffia and later local cotton provided by farmers. By the 17th century, weaving had become established in Bonwire, Ashanti.

Traditionally, women prepared the fibres by spinning cotton, while men handled the weaving process, setting the warp and went on a four-heddle loom. Early kente also incorporated local Okanantan spider silk, which was later supplemented or replaced by imported European silk, sometimes mixed with cotton yarns. The complex design and production methods, including the use of specific loom components, highlight kente's profound historical and cultural significance as a mobile cultural heritage item essential for preservation, study, and public education.



Figure 10.1: Kente, a typical Ghanaian fabric.

2. Traditional textiles with handmade prints (Adinkra)

Adinkra motifs serve as a powerful form of cultural expression, filled with deep symbolic meaning derived from both representational natural objects and abstract concepts. These designs, traditionally stamped onto fabric, communicate profound philosophical ideas and proverbs. For example, specific shapes like the oval convey concepts of holiness, femininity, and beauty, while a half-circle or crescent is associated with fertility. Other symbols carry equally significant messages: the cross embodies compassion, and the arrow signifies a new beginning. Beyond general cultural meaning, adinkra cloth was historically tailored to express a monarch's personal philosophy. A king's choice of aya (a fern-patterned) fabric, for instance, specifically communicated his fearlessness. Through this intricate visual language, adinkra textiles become wearable declarations of identity and wisdom.



Figure 10.2: Some *adinkra* symbols and their meaning.

Processes involved in the production of indigenous Adinkra textiles

1. **Fabric sourcing and preparation:** The foundation of adinkra cloth is typically cotton fabric. Traditionally, this cotton would be woven locally. The fabric chosen can either be white (for a strong contrast with the dark stamp) or pre-dyed to a characteristic rusty brown colour. This brown hue is specifically known as kuntunkuni, a name derived from the tree whose bark provides the dye.
2. **Dye preparation:** The distinctive dark dye used for stamping Adinkra motifs is prepared from the bark of a specific indigenous tree, the kuntunkuni tree (scientifically known as *Bombax brevicuspe*). The process involves boiling or steeping the bark for an extended period to extract its rich dark pigments. This extract is then reduced and

prepared into a thick, dark, inky dye solution that is suitable for stamping. The quality and depth of this dye are crucial for the clarity and longevity of the adinkra symbols.

3. **Motif stamp carving:** Before stamping can begin, the adinkra motifs themselves must be prepared. These intricate symbols are traditionally carved onto small, durable pieces of calabash gourd or wood. The carving process creates a raised relief of the desired symbol.

   Each specific adinkra symbol has a predefined meaning and shape, requiring precise carving skills to ensure accuracy and detail when transferred to the fabric. Each stamp usually has a handle for easy gripping.

4. **Stamping process (Application):** The chosen cotton fabric (white or kuntunkuni brown) is laid out smoothly, usually on a flat surface or a stretched frame. The carved adinkra stamp is then dipped into the prepared dark dye solution, ensuring an even coating of dye on the raised pattern. The dye-laden stamp is then physically pressed firmly and carefully onto the fabric. This action transfers the dark motif onto the cloth. The artisan works systematically, repeating the stamping process across the entire fabric to create a coherent and often repetitive pattern, or to strategically place specific symbols.

5. **Drying and finishing:** After the stamping is complete, the fabric is traditionally laid out to dry in the sun. The heat of the sun aids in fixing the dye to the cotton fibres, making it more permanent. Once completely dry, the adinkra cloth may undergo a final rinsing to remove any excess dye or residue, which helps to further set the colour and ensures the patterns are crisp and clear.

Activity 10.1 Examining some indigenous textiles in Ghana

Aim: To engage learners in massive research on some Ghanaian textiles and their significance.

What to do

1. In small groups of three or four, carry out research into various types of Ghanaian indigenous textiles.
2. In the same groups, discuss the textiles and highlight their cultural significance, traditional methods, and scientific principles involved in their production.
3. In the same groups, create visual aids like posters, diagrams, or digital presentations to illustrate key concepts and findings.

Discussions: Learners present their posters, diagrams and digital presentations for class discussion and display for a gallery walk.

SCIENTIFIC PRINCIPLES INVOLVED IN ADINKRA TEXTILE PRODUCTION

Dye chemistry and pigment extraction

a. **Biochemical extraction (Leaching):** The characteristic dark, rusty-brown dye for adinkra is extracted from the bark of the kuntunkuni tree (*Bombax brevicuspe*). This process typically involves boiling or prolonged steeping of the bark in water. Scientifically, this is a form of leaching, where soluble organic compounds (the dye pigments, or chromophores) are extracted from the plant material into the hot water. The bark contains complex molecules, likely tannins (a class of polyphenols) and other natural organic pigments, which are responsible for the colour.

b. **Dye solution formulation:** The extracted liquid is then processed into a thicker, inky consistency suitable for stamping. The stability and viscosity of this dye solution are critical for clear motif transfer.

c. **Dye-metal interactions (Potential mordanting):** While the provided text doesn't explicitly mention a mordant for adinkra dye, many natural brown dyes, particularly those rich in tannins, form stable complexes with metal ions. If the dye pots are made of iron, or if the water used contains dissolved iron, a chelation reaction could occur, where the dye forms insoluble coordination complexes with iron ions (Fe^{3+}), enhancing colour fixation and contributing to the characteristic "rusty brown" or dark brown/black hue. This type of reaction significantly improves the dye's wash-fastness (measure of the dye's resistance to fading when washed) and light-fastness (how well a fabric retains its colour when exposed to light).

Material science of fabric-dye Interaction

a. **Cellulose fibre adsorption:** Adinkra predominantly uses cotton fabric, which is composed primarily of cellulose fibres. Cellulose fibres are hydrophilic (water-loving) due to their hydroxyl (-OH) groups. The dye molecules adhere to these cellulose fibres through various intermolecular forces, including hydrogen bonding and van der Waals forces, which allow the dye to be physically adsorbed onto and within the fibre structure.

b. **Capillary Action:** it the ability of a liquid to flow in narrow spaces without the assistance of external forces. When the liquid dye is applied to the fabric, it spreads outward from the point of contact into the surrounding fibres through capillary action. This phenomenon, driven by the surface tension of the liquid and the adhesive forces between the liquid and the narrow inter-fibre spaces, dictates the sharpness or slight bleeding of the stamped motif's edges.

Physical principles of stamping (Direct application)

a. **Pressure and transfer:** The act of physically pressing the carved adinkra stamp onto the fabric is governed by principles of pressure (force per unit area) and adhesion. The dye solution adheres to the raised surfaces of the stamp. When the stamp is pressed onto the fabric, the pressure ensures intimate contact, facilitating the direct transfer of dye from the stamp to the fabric.

b. **Surface tension control:** The viscosity and surface tension of the dye solution are carefully balanced through traditional preparation methods to ensure that the dye adheres well to the stamp without dripping excessively and transfers cleanly to the fabric without blurring the fine details of the motif.

Drying and dye fixation

a. **Evaporation:** After the motifs are stamped, the fabric is typically laid out to dry. This process primarily involves the evaporation of the water molecules (solvent) from the dye solution, leaving the solid dye particles physically trapped within the fabric fibres.

b. **Photochemical reactions (Sunlight):** Exposure to sunlight during drying can also play a role. The heat from the sun can further assist in the drying process, while ultraviolet (UV) radiation can induce photochemical reactions in some natural dyes, contributing to the final colour development and enhancing the dye's permanence and resistance to fading.

Processes involved in the production of indigenous tie-and-dye textile

Tie-dye, a traditional textile art, boasts a rich history spanning centuries and continents, found in diverse cultures across Asia, Africa, and potentially Latin America. This marvellous technique involves using thread to bind bundles of fabric tightly before dyeing, creating intricate designs through the resist method. Across West Africa, from Senegal to Nigeria, including countries like Ghana, Mali, and Sierra Leone, tie-dye traditions like Gara and Adire are integral to the cultural landscape, utilizing either natural or synthetic dyes to produce their incredible patterns.

1. **Fabric Preparation:** The process typically begins with natural fibres, most commonly cotton, due to its absorbency and durability. Silk and rayon are also used in some traditions. The fabric is thoroughly washed to remove any impurities, sizing agents, or natural oils that might hinder dye absorption. It can then be left damp or dried, depending on the desired crispness or blending of the final pattern. For some Adire variations, the fabric might be pre-dyed to a base colour, such as the kuntunkuni brown.
2. **Resist application (tying, folding, stitching, waxing or pasting):** This is the defining stage of tie-dye, where specific areas of the fabric are physically prevented from absorbing dye. Artisans employ a variety of ingenious methods, which are:

    a. **Tying (e.g., Adire oniko, Gara):** Sections of the fabric are tightly bound with raffia, thread, string, or rubber bands. Small objects like stones, seeds, or corn

kernels might be tied inside the fabric to create distinct circular or oval patterns. Folding the cloth into complex patterns (like a concertina or spiral) before tying creates geometric designs. The tightness and placement of the ties directly determine the pattern's sharpness and size.

b. **Stitching (e.g., Adire alabere):** Fine stitches are sewn into the fabric along a desired pattern line, and the thread is then pulled taut to gather and compress the fabric. This creates linear, curved, or more elaborate stitched resist patterns.

c. **Starch pasting (e.g., Adire eleko):** A thick, viscous paste, traditionally made from cassava or maize flour, is hand-painted or stencilled onto the fabric. When this paste dries, it forms a physical barrier that the dye cannot penetrate.

d. Waxing (Batik): Melted wax is applied to the fabric using specialized tools (like a canting for fine lines or a cap for stamping). The hydrophobic wax solidifies and creates a barrier against the water-based dye.

3. **Dye preparation**

a. **Natural dye extraction:** Traditional tie-dye heavily relies on natural dyes.

Indigo: Leaves from the indigo plant (*Lonchocarpus cyanescens* or *Indigofera tinctoria*) are collected, often pounded, and then allowed to ferment in large earthenware dye pots, typically partially sunk into the ground. This fermentation process is a crucial chemical reduction, transforming the insoluble blue indigo into a soluble, yellowish-green "leuco-indigo" form. Wood ashes or caustic soda might be added to soften water and maintain alkalinity, vital for the dyeing process.

b. **Kola nut:** Kola nuts are finely crushed, usually with a mortar and pestle, and mixed with water and wood ashes (acting as a mordant/fixative) to produce a brown dye. This dye bath is labour-intensive to prepare and has a shorter usable life compared to indigo.

c. **(Immersion and oxidation):** The fabric, with its applied resists, is carefully immersed into the prepared dye bath. For indigo, the fabric is left in the soluble leuco-indigo solution to absorb the dye. Upon removal and exposure to air (oxygen), the leuco-indigo rapidly undergoes an oxidation reaction, reverting to its insoluble, vibrant blue form that is permanently trapped within the fabric fibres. The depth and richness of the blue hue are controlled by the number of times the fabric is dipped; the more immersions, the darker the indigo becomes. For kola nut dye, the fabric absorbs the brown colour directly from the solution. Sometimes, fabrics are over-dyed (e.g., dipped in kola nut dye first, then in indigo) to create complex multi-tonal effects like dark greens or greenish-blacks.

d. **Removal of resist and finishing:** Once the dyeing process is complete and the dye is fixed (often by drying), the resist materials are removed. For tied fabrics, the strings, raffia, or rubber bands are untied. For stitched fabrics, the threads are carefully cut and pulled out. For starch-resist Adire eleko, the dried cassava paste is scraped or washed off. For batik, the wax is typically removed by boiling the fabric in water, which melts the wax, allowing it to be skimmed off, followed by a thorough washing.

Scientific principles involved in tie-dye textile production

1. **Physical principle of resist application**
   a. **Mechanical barrier & pressure:** The core of tie-dye involves physical manipulation of the fabric (tying, folding, twisting, knotting, stitching). These actions create a mechanical barrier by compressing and densifying the fabric in specific areas. The pressure exerted by the ties (e.g., raffia, string, rubber bands) physically blocks dye molecules from penetrating the tightly bound regions. This also reduces the pore space and hinders capillary action within those compressed areas.
   b. **Hydrophobicity (wax resist in batik/related methods):** In techniques like Batik (which uses a similar resist principle), melted wax is applied. Wax is hydrophobic (water-repelling), creating an impermeable physical barrier against the aqueous dye solution.
   c. **Physical blockade (starch/clay resist):** In some forms, a thick paste (e.g., cassava starch) is applied. This paste dries to form a physical solid layer that mechanically blocks dye penetration.

2. **Fibre chemistry and dye adsorption/Binding**
   a. **Cellulose fibre structure (Cotton):** Most traditional tie and dye fabrics are made from cotton, which is composed primarily of cellulose (a polymer of glucose units). Cellulose fibres contain numerous hydroxyl (-OH) groups, making them hydrophilic (water-attracting) and capable of interacting with dye molecules.
   b. **Dye molecule properties (chromophores & auxochromes):** Dyes contain chromophores (chemical groups responsible for colour by absorbing certain wavelengths of white light) and auxochromes (functional groups that enhance solubility and aid in binding to fibres).
   c. **Dye-fibre bonding:** The permanence of the dye depends on the type of bond formed.
      i. **Covalent Bonding:** Modern synthetic fibre-reactive dyes form strong, permanent covalent bonds with cellulose fibres under specific pH conditions (e.g., alkaline conditions created by soda ash). This is the most robust type of bonding, leading to high wash-fastness.
      ii. **Hydrogen bonding & van der Waals forces:** Many natural dyes (like indigo or kola nut) and some synthetic dyes bind through weaker hydrogen bonds (between dye and cellulose hydroxyls) and van der Waals forces (general intermolecular attractions). These are less permanent than covalent bonds but still effective.
      iii. Mordanting (chemical bridges): For many natural dyes (e.g., kola nut dye), a mordant (e.g., wood ashes containing metal salts like aluminium or iron compounds) is crucial. Mordants act as chemical bridges by binding to both the dye molecule and the fibre, forming a stable coordination complex. This

enhances the dye's adherence, lightfastness, and often modifies the final colour.

3. **Dye bath chemistry (pH, reduction-oxidation for indigo)**
   a. **pH control:** The pH of the dye bath is often critical for optimal dye uptake and reaction. For example, fibre-reactive dyes require an alkaline environment (high pH) for their reaction with cellulose. Acid dyes (used for protein fibres like wool/silk) require acidic conditions.
   b. **Redox reactions (indigo dyeing):** Traditional indigo dyeing involves sophisticated reduction-oxidation (redox) chemistry.
      i. **Reduction:** In its natural state, indigo (indigotin) is an insoluble blue. To be used, it must be chemically reduced (e.g., through fermentation of leaves or by adding reducing agents like sodium hydrosulphate) in an alkaline environment. This converts it into a soluble, yellowish-green form called leuco-indigo (or indigo white).
      ii. **Oxidation:** The fabric is immersed in this soluble leuco-indigo solution. Upon removal from the dye bath and exposure to air (oxygen), the leuco-indigo rapidly oxidises back to its insoluble blue form (indigotin), which then precipitates and becomes physically trapped within the fabric fibres, creating the permanent blue colour. This is why the colour develops upon exposure to air.

4. **Physical processes during dyeing and finishing**
   a. **Diffusion & capillary action:** Dye molecules move from areas of high concentration (dye bath) into the fabric fibres (lower concentration) through diffusion. Within the fabric, dye solution spreads through the tiny spaces between fibres by capillary action.
   b. **Evaporation:** During drying, water evaporates from the dyed fabric, leaving the dye solids embedded within the fibres.
      i. **Mechanical Fixation:** Techniques like beating the cloth with a mallet (e.g., after indigo dyeing) can physically press dye particles deeper into the fibres and increase the fabric's sheen by compacting the fibres.
      ii. Heat transfer (wax removal): In wax-resist methods (like batik), removing the wax involves heat transfer (boiling water) to melt the wax, exploiting its lower density to separate it from the fabric.

Activity 10.2 A Visit to A Tie and Dye Textile Production Facility

Objective: To help learners acquire firsthand information on the processes involved in tie-dye textile production.

What to do

1. Observation and documentation of key processes involved.

2. Hands-on interactions with equipment, materials, and production personnel (if permitted), to foster a deeper understanding of real-world applications of concepts and scientific principles involved in the production.

Discussions

1. In pairs, learners prepare a flowchart of the kente production process based on their interaction with the production facility.
2. Learners compare and discuss their flow charts in a class interaction.
3. Learners explain the scientific principles behind the processes observed and are made to offer suggestions on how to improve those processes for a better production process.

BATIK

Batik fabric-making is a wax-resist dyeing technique done by hand, usually in homes and small workshops by families or small groups of dealers.100% cotton fibre is used. From cotton grown in the dry savannah climate of northern Ghana, the plain fabric is made in factories up there in northern Ghana. Either calico or grey baft is used, the former being softer. The fabric dyes are imported.

Steps In Batik Fabric-Making

1. **Pre-shrinking**: The cloth is pre-shrunk, due to the dyeing, washing and re-dyeing process. Hand-dyed & hand-printed, they are suitable for a wide variety of projects. Sometimes light damask fabric is used, and those have a slight shimmer to the finished product. They have strong, vibrant colours with abstract or Ghanaian designs.
2. **Wax application**: Melted wax is applied to the fabric in a design of the batik maker's choice with a brush or pre-carved wooden block. Starting with a lighter colour, the cloth is dipped in the first dye and then dried. Wherever the wax has seeped through the fabric, the dye will not penetrate; the rest is the new colour. More wax is applied for the next set of designs, followed by dyeing and drying until the complete number of colours and designs has been achieved. (Often several colours are used, with a series of waxing and dyeing steps.)
3. Boiling: The fabric is boiled to remove the wax for re-use, and to reveal the deep, rich colours and the fine crinkle lines that give batik its character. The last stages involve a final drying and ironing for sale.

A few of them have two designs on the same piece, meant to complement each other. One fabric is an accent to the other.

Processes Involved In The Production Of Indigenous Batik

1. **Fabric Preparation:** The process typically begins with natural fabrics, most commonly cotton or sometimes silk, due to their absorbency and suitability for wax application. The fabric is thoroughly washed to remove any impurities, starches, or sizing agents that could interfere with dye absorption or wax adherence. It is then often stretched taut on a frame to ensure a smooth, stable surface for intricate wax application.
2. **Design, planning and transfer (optional but common):** While some skilled artisans may apply wax freehand, designs are often sketched onto the fabric lightly with a pencil or charcoal. For complex or repetitive patterns, a pre-made design might be traced or stamped onto the fabric.
3. **Wax preparation and application (The resist)**
    a. **Wax melting:** A blend of waxes (traditionally beeswax for flexibility and paraffin wax for its characteristic crackle effect) is melted in a wax pot over a heat source, maintaining it at a consistent, hot liquid state.
    b. **Wax application:** The melted wax is then applied to the fabric using specialized tools.
        i. **Canting (Tjanting):** A pen-like tool with a small copper reservoir and a fine spout, used for drawing intricate lines, dots, and detailed patterns by hand. This is known as *batik tulis* (written batik).
        ii. **Cap (Tjap):** A copper stamp with a carved design, used for applying repetitive patterns more quickly and consistently over larger areas. This is known as *batik cap* (stamped batik).
        iii. **Brushes:** Used for applying larger areas of wax or broader strokes.
4. **Resist mechanism:** The wax, being hydrophobic (water-repelling), solidifies upon contact with the fabric, forming an impermeable barrier. This ensures that when the fabric is dyed, the areas covered by wax resist the dye and retain their original colour.
5. **Dyeing (Lightest colour first):** Once the wax has hardened, the fabric is immersed in a dye bath. The dye molecules only penetrate and colour the unwaxed areas of the fabric. Dyeing proceeds as follows:
    a. **Colour progression:** Batik dyeing typically proceeds from the lightest colours to the darkest. The first dye bath will be the lightest desired colour.
    b. **Fixation:** Dyes are allowed to absorb, and for many synthetic dyes, a fixing agent (like soda ash) is used to create a permanent bond with the fabric fibres. Natural dyes (like indigo, kola nut) have their own specific preparation and fixation methods.
    c. **Drying:** After dyeing, the fabric is carefully removed from the dye bath and hung to dry completely. Wringing or squeezing is avoided to prevent the wax from cracking prematurely, unless the crackle effect is desired at this stage.
6. **Repeated waxing and dyeing (for multi-colour designs):** For multi-coloured batik, the process of waxing and dyeing is repeated in layers. After the first dye colour has

dried, additional wax is applied to areas that are to retain that first colour. The fabric is then dyed in a darker colour. This process can be repeated multiple times, applying new wax to protect previously dyed areas and progressively introducing darker shades. The distinctive "crackle effect" often seen in batik is created by deliberately crinkling or manipulating the fabric after a layer of wax has hardened, causing the wax to crack. When the fabric is then dyed, the dye seeps into these fine cracks, creating a network of fine lines of the new colour within the waxed areas.

7. **De-waxing (wax removal):** Once all the desired colours have been applied and dried, the wax resist must be removed. The most common traditional method is to immerse the fabric in boiling water. The heat causes the wax to melt and separate from the fabric. Since wax is less dense than water, it floats to the surface, where it can be skimmed off (and often reused). In some methods, ironing the fabric between layers of absorbent paper (like newspaper) can also remove wax, as the paper absorbs the melted wax.
8. **Final washing and finishing:** After de-waxing, the fabric is thoroughly rinsed in warm water with soap to remove any residual wax and unbound dye. It is then dried and may be pressed or ironed to smooth out wrinkles and achieve the final desired finish.



Figure 10.3: Some Ghanaian batik fabric.

Scientific Principles Involved In Batik Textile Production

1. **Physical principle of wax as a resist**
   a. **Hydrophobicity:** This is the core principle of batik. Wax is a hydrophobic (water-repelling) substance, meaning it does not mix with water. When applied to fabric, the melted wax solidifies and forms an impermeable physical barrier.

This barrier prevents the aqueous dye solution from penetrating the waxed areas, leaving them undyed.

b. **Melting and solidification:** Wax has a relatively low melting point. It is applied to the fabric in its liquid (molten) state, allowing for intricate drawing or stamping. Upon cooling, it rapidly solidifies, creating a stable, physical mask on the fabric surface.

c. **Viscosity and adhesion:** The consistency (viscosity) of the melted wax (often a blend of beeswax for flexibility and paraffin for brittleness/crackle) is crucial. It must be viscous enough to cling to the fabric without excessive spreading but fluid enough to flow smoothly from tools like canting (for fine lines) or tjap (for stamping). It adheres to the fabric fibres through various intermolecular forces.

2. **Fabric chemistry and dye adsorption/Binding**

a. **Cellulose fibre (Cotton):** Batik predominantly uses natural cellulose fibres like cotton. These fibres are hydrophilic (water-absorbing) and have numerous hydroxyl (-OH) groups that are receptive to dye molecules.

b. **Dye-fibre interaction:** The way dyes bind to the fabric is chemical. Dyes contain chromophores (colour-bearing groups) and auxochromes (groups aiding solubility and binding).

i. **Covalent bonding:** For synthetic fibre-reactive dyes often used today, the dye forms strong, permanent covalent bonds with the cellulose fibres, typically in an alkaline environment (e.g., pH adjusted by soda ash).

ii. **Hydrogen bonding/Physical adsorption:** Many natural dyes, and some synthetics, bind through weaker intermolecular forces like hydrogen bonds and van der Waals forces.

c. **Capillary action:** The dye solution is drawn into the unwaxed areas of the fabric through capillary action, filling the microscopic spaces between and within the fibres.

3. **Dye chemistry (especially for traditional dyes like indigo)**

a. **Solubility and redox reactions (indigo):** If traditional indigo dye is used, complex reduction-oxidation (redox) chemistry is involved. Natural indigo (indigotin) is insoluble in water. It must be chemically reduced (e.g., through fermentation in an alkaline vat) to a soluble, yellowish-green form (leuco-indigo). When the fabric is removed from the vat and exposed to oxygen in the air, the leuco-indigo rapidly oxidises back into its insoluble blue form, becoming permanently trapped within the fabric fibres.

b. **Mordanting (for certain dyes):** While not universally required for all batik dyes, some natural dyes need mordants (metal salts like alum or iron) to act as chemical "bridges" that help fix the dye permanently to the fabric, improving colour-fastness by forming stable coordination complexes.

Physical Processes During Dyeing And Layering

1. **Sequential dyeing (light to dark):** The multi-colour effects in batik are achieved by a precise sequence of waxing and dyeing, typically moving from the lightest dye colours to the darkest. Each colour is applied only to the unwaxed areas, and then new wax is applied to protect those newly dyed areas before immersing the fabric in a darker dye bath.
2. **Drying and evaporation:** After each dyeing stage, the fabric is dried, allowing the water to evaporate and leaving the dye solids embedded in the fibres.
3. **Wax removal (de-waxing) and finishing**
    a. **Heat transfer and phase change:** The wax resist is removed, usually by immersing the fabric in boiling water. This applies heat, causing the wax to undergo a phase change from solid to liquid.
    b. **Density difference:** Since melted wax is less dense than water, it floats to the surface, allowing it to be skimmed off (and often recycled).
    c. **Solvent removal (alternative):** In some modern methods, chemical solvents might be used to dissolve the wax, which also relies on solubility principles.
    d. **Final washing:** A thorough wash with soap and hot water removes any residual wax and unbound dye particles, ensuring a clean, vibrant final product.
4. **Crackling effect (physics of fracture):** The distinctive "crackle" lines in some Batik designs are achieved by mechanically manipulating the fabric after the wax has been applied and hardened (e.g., crumpling or folding). This induces tiny fractures or cracks in the brittle wax layer. When the fabric is then dyed, the dye seeps into these fine cracks, creating the characteristic network of lines.

ADIRE TECHNIQUES

Adire are indigo-dyed cotton cloths decorated using a resist-dying technique to create striking patterns in blue and white. They were traditionally made and worn by women throughout Ghana and West Africa. The cloths were usually made up of two strips of factory-produced cotton, sewn together to form a shape that was roughly square, and worn as wraps around the body. Cloths were made up of two strips of factory-produced cotton shirting sewn together to form a shape that was roughly square. They were generally worn by women as wrappers. One of the most important factors in the popularity of adire during the 1960s was that a large number of cloths could be produced quickly and cheaply in response to changing customer demands. It has now however fallen out of favour.

Cloths were usually prepared and dyed, by women, and treated in a variety of ways to create patterns that would be revealed after dying. Raffia and starch were the two most common forms of resist used in the production of adire.

Adire techniques proceed as listed below.

1. **The dyeing process**

   The cloths are usually prepared, and always dyed, by women. Their bright colour comes from imported indigo grains or locally-grown indigo leaves, which are fermented and mixed with water softened with caustic soda to make a dye. The cloth is dipped into a large pot of dye, and then pulled out to allow it to oxidise, a process which can be repeated to make the colour darker. Sometimes after dyeing it, the cloth is beaten with a mallet to make it shine softly (give it sheen).

2. **Creating pattern**

   Before dyeing, the fabric is treated in a variety of ways to prevent certain parts of it from absorbing dye. This will create the patterns revealed after the dyeing process. Raffia and starch are the two most common forms of resist-dyeing used. Tying raffia around the cloth, a process known as àdìrẹ̀oniko, can produce a huge variety of patterns. For example, tying small stones or seeds into the cloth will create small circles, or larger circles can be made by lifting a point of fabric and binding the fabric beneath it tightly.

   A pattern formed of a specific combination of circles is given a name; the pattern name often varies from town to town or changes over time. One example made in Ibadan in the 1960s features five rows of large circles with small circles filling the rest of the cloth, a pattern known there as olosupaeleso, which means “moons and fruits”.



Figure 10.4: Adire fabric.

Adire, The Art Of Raffia Resist Dyeing

Adire represents a captivating facet of traditional textile production, where the humble raffia fibre is masterfully employed to create intricate resist-dyed patterns. This technique, a subcategory of the broader adire (tie-dye) tradition, is renowned for its versatility and the stunning array of designs it yields, often in vibrant indigo blue and contrasting white.

At its core, adire oniko is a mechanical resist dyeing method. This means that patterns are formed by physically binding or tying sections of the fabric very tightly with raffia (or sometimes thread) before the cloth is immersed in a dye bath. The tightly bound areas act as a physical barrier, preventing the dye solution from penetrating the fabric fibres underneath. This creates sharp, undyed patterns against the dyed background.

Crafting Patterns With Raffia, Techniques And Variations

A remarkable variety of patterns can be produced by varying the way the raffia is applied as follows:

1. Creating circles
    a. Smaller circles: Artisans often tie small stones or seeds directly into the cloth. The tightness of the knot around the object creates a small, defined circular resist, resulting in crisp white dots against the dyed background.
    b. Larger circles: For bigger circular motifs, a point of fabric is lifted, and the fabric directly beneath it is bound tightly with raffia. The size of the lifted and bound area determines the diameter of the resulting circle.

2. Achieving linear and geometric patterns:
    a. **Concertina folding (Accordion pleating):** One highly effective technique involves meticulously folding the cloth from corner to corner like a concertina (an accordion-like pleat). Once folded, the entire length of the pleated cloth is then bound very tightly at various, evenly spaced points along its length. When this tightly bound, folded cloth is dyed, the dye only saturates the exposed areas between the bindings. The bound sections remain undyed.

    Upon unfolding and unbinding the cloth, this method creates a striking diamond-shaped pattern with alternating blue and white stripes. The broadness of these stripes can be precisely controlled by adjusting the intervals at which the cloth is bound. Tighter, closer bindings produce finer stripes, while looser, more spaced bindings result in broader stripes.
    b. **Beyond simple shapes**: The ingenuity of adire oniko extends to much more complex designs. Artisans might combine various tying methods, incorporate intricate knotting techniques, or strategically pleat and bind the fabric to achieve highly detailed geometric motifs, abstract compositions, or even figurative representations.

3. The dyeing process
    a. Traditionally indigo: While modern adire may use synthetic dyes, the traditional and most revered adire oniko employs natural indigo dye. This involves a multi-step chemical process:
    b. Preparation of the indigo vat: Natural indigo dye is insoluble in water in its vibrant blue form. It must be chemically reduced in an alkaline solution (traditionally through fermentation using ingredients like ash, local sweeteners, and bacteria) to a soluble, yellowish-green form called leuco-indigo.

c. **Dyeing immersion**: The raffia-bound cloth is carefully immersed in this leuco-indigo dye bath. The soluble dye penetrates the unwaxed/unbound fibres.

d. **Oxidation**: Upon removal from the dye bath, the leuco-indigo rapidly oxidizes when exposed to air (oxygen). This chemical reaction converts it back into its insoluble blue form, effectively trapping the colour within the fabric fibres**.**

e. **Repeated dipping:** To achieve deeper and richer shades of blue, the fabric is typically dipped multiple times, allowing it to oxidize between each dip, sometimes requiring dozens of immersions.

4. **Unbinding and finishing:** After the desired depth of colour is achieved and the fabric is fully oxidized and dried, the raffia bindings are carefully removed, revealing the intricate white patterns against the deep blue background. The cloth is then rinsed and washed to remove any excess dye.

The meticulous handwork involved in the tying and folding, combined with the transformative chemistry of the indigo vat, makes adire oniko a testament to the scientific and artistic heritage embedded in indigenous textile traditions. The popularity of specific designs, like the "cloth of the year" in 1964, further highlights the cultural significance and dynamic evolution of this ancient craft.

Stitch resist

The term adire alabare is used when sewing has been used as a means to resist the dye. If the sewing has been done with raffia, then it would be a form of adire oniko. Both machine sewing and hand sewing could be used to produce patterns. Although adire cloths are usually made by women, those produced using sewing machine are made by men. When two pieces of dyed cloth are stitched together, it creates a diamond shaped pattern with alternating blue and white stripes. The broadness of the stripes can be varied by the intervals at which it is bound.

Adire

Adire encompasses various resist-dyeing techniques primarily practiced by the Yoruba people of South-Western Nigeria. It traditionally uses natural indigo dye and different resist materials.

Types of Adire and their resist mechanisms

1. **Adire Oniko (Tying/Knotting):** Involves tying raffia, thread, or individual corn kernels/pebbles tightly around sections of fabric. The fabric can also be twisted or folded and tied.

   Scientific process: Similar to tie-dye, this is a mechanical resist. The physical compression and tight wrapping create a barrier that prevents dye penetration or allows only limited seepage, resulting in circular, striped, or irregular patterns.

2. **Adire Alabere (Stitching) Resist:** Patterns are created by stitching raffia or thread tightly into the fabric in a specific design (e.g., lines, curves, motifs). The fabric is then gathered tightly along these stitched lines.

Scientific process: This is also a mechanical resist based on physical tension and compression. The tightly stitched areas are inaccessible to the dye solution. After dyeing, the raffia/thread is removed, revealing the undyed pattern.

3. **Adire Eleko (Starch paste resist):** A paste made from cassava starch (or rice starch) and other ingredients (e.g., alum, copper sulphate) is painted onto the fabric. The paste hardens upon drying.

   Scientific process: This is a physical barrier resist**.** The thick, dried starch paste creates an impermeable layer that physically blocks the dye from reaching the fabric fibres underneath. The paste acts as a non-reactive coating.

   Dyeing process (Traditionally indigo): Traditional Adire uses natural indigo dye, typically extracted from plants like Lonchocarpus cyanescens. Indigo is a vat dye.

   Reduction: Indigo dye is insoluble in water in its natural (oxidized) blue form. To be used, it must be chemically reduced in an alkaline solution (e.g., with natural reducing agents like fermentation by bacteria in a traditional indigo vat, or synthetic reducing agents like sodium hydrosulphite in modern use). This turns it into a soluble, yellowish-green form called leuco-indigo**.**

   Dyeing: The fabric (with resist applied) is immersed in this leuco-indigo dye bath. The leuco-indigo molecules penetrate the fibres.

   Oxidation: When the fabric is removed from the dye bath and exposed to air (oxygen), the leuco-indigo rapidly oxidizes back to its insoluble blue form, becoming trapped within the fibres. This oxidation reaction is what "fixes" the blue colour.

   Repeated dyeing: To achieve deeper shades of blue, the fabric is repeatedly dipped into the indigo vat and exposed to air for oxidation, sometimes 25 or more times for a deep blue-black.

   Removal of resist: For adire eleko, the dried cassava paste is scraped or washed off after dyeing, revealing the undyed patterns.

Scientific principles involved in Adire textile production

1. **Physical principles of resist application:** Adire employs various techniques to create patterns by physically preventing dye from reaching certain areas of the fabric.

   a. **Mechanical compression (Adire Oniko & Adire Alabere):**

      i. **Principle:** This relies on applying pressure and physical barriers to the fabric. In adire oniko (tying/knotting), sections of the fabric are tightly bound with raffia, thread, or string, often incorporating small objects like stones or seeds. In adire alabere (stitching), patterns are created by sewing intricate lines with raffia or thread, then pulling the threads taut to gather and compress the fabric.

      ii. **Mechanism:** The tight binding or stitching physically compresses the fabric fibres, significantly reducing the pore space between threads and fibres. This high local pressure and reduced porosity physically block the larger dye molecules from penetrating the treated areas. Additionally, the compressed fabric has less surface area exposed to the dye solution, hindering dye uptake.

b. **Physical barrier/Adsorption (Adire Eleko - Starch resist)**

i. **Principle:** This method utilizes a thick paste, traditionally made from cassava starch, as a physical block.

ii. **Mechanism:** The starch paste is applied to the fabric, forming an impermeable, solid layer upon drying. Starch molecules (complex carbohydrates) form a dense network that physically obstructs the dye molecules from reaching the fabric fibres underneath. The paste adheres to the fabric but does not chemically react with it or the dye in a way that allows colour transfer. After dyeing, the dry paste is brittle and can be scraped off or washed away, revealing the undyed pattern.

c. **Dye chemistry (Primarily traditional indigo vat dyeing):** Traditional adire is renowned for its use of natural indigo dye, which involves a complex and fascinating series of chemical reactions.

d. **Biochemical reduction (Fermentation):** Natural indigo (indigotin), extracted from plants like Lonchocarpus cyanescens (Yoruba: elu) or Indigofera tinctoria, is insoluble in water in its vibrant blue form. To make it usable for dyeing, it must undergo a chemical reduction process. Traditionally, this is achieved through fermentation in a deep earthenware dye vat. Microorganisms (bacteria) consume sugars and other organic matter in the vat, creating an anaerobic (oxygen-free), alkaline environment (often maintained with wood ash or caustic soda) and producing reducing agents. These agents chemically reduce the insoluble blue indigotin to a soluble, yellowish-green form called leuco-indigo (or indigo white).

e. **Alkalinity:** The alkaline (high pH) environment of the indigo vat is crucial for both the reduction process and for keeping the leuco-indigo soluble and stable until it is absorbed by the fabric.

f. **Oxidation for colour fixation:** When the fabric is removed from the dye bath, the soluble leuco-indigo molecules that have penetrated the fibres are exposed to oxygen in the air. This triggers a rapid oxidation reaction, where the leuco-indigo is chemically converted back into its insoluble blue indigotin form. This insoluble pigment precipitates and becomes physically trapped within the fabric fibres, permanently colouring the cloth blue. The intensity of the blue colour is directly proportional to the number of times the fabric is dipped and air-dried.

g. **Dye-fibre interaction:** The leuco-indigo molecules interact with the cellulose fibres of the cotton through various intermolecular forces while in the vat. Once oxidised, the insoluble indigotin is mechanically entrapped within the fibre matrix, making it highly wash-fast.

2. **Material Science (Fabric properties)**

Cellulose fibre structure (Cotton): As with other natural fibre textiles, the cellulose structure of cotton fabric, with its numerous hydroxyl groups, plays a vital role in adsorbing the leuco-indigo solution. The porous nature of the woven fabric allows for efficient penetration of the dye into the unwaxed areas.

3. **Physical processes in application and finishing**
   a. Diffusion and capillary action: The dye solution spreads into the unwaxed portions of the fabric through diffusion (movement from high to low concentration region) and capillary action (the wicking of liquid into the narrow spaces of the fabric).
   b. Evaporation: After dyeing, the fabric is dried, a process of evaporation that removes the water solvent, leaving the dye solids fixed.
   c. Mechanical compaction: For some indigo-dyed fabrics, beating the cloth with a mallet after drying can help compact the fibres, enhance the dye's adherence, and impart a sheen (soft lustre).

Activity 10.3 Research Factors Involved in Textile Production

Produce a single-page summary (mind-map or short essay) about the following in relation to textile production in Ghana

1. Sustainable practices
2. Safety regulations
3. Market trends
4. Community impacts

Activity 10.4 Diamond Nine Task on Indigenous Texture Production

Instructions: Below are nine statements about the economic importance of indigenous textile production. Arrange them in a diamond nine formation.

- 1 at the top (most important)
- 2 below
- 3 in the middle
- 2 below that
- 1 at the bottom (least important).

Be ready to explain why you ranked them in that order.

Statements to Rank

1. Provides a source of income and employment for local artisans and families.
2. Supports cultural tourism and attracts visitors seeking authentic heritage products.
3. Encourages sustainable, small-scale production with low environmental impact.
4. Strengthens national identity and pride, adding value to local economies.
5. Offers export opportunities, boosting foreign exchange earnings.
6. Reduces dependency on imported textiles and promotes self-reliance.

7. Preserves traditional skills that can be passed down to future generations.
8. Provides affordable, locally produced clothing for rural and urban communities.
9. Stimulates related industries such as natural dye farming, weaving tool production, and local markets.

REVIEW QUESTIONS

1. List and explain the processes involved in adinkra production.
2. Discuss the steps involved in batik fabric making.
3. How do scientific principles apply to adire textile production?

ANNEXES - OBSERVATIONS AND THEIR EXPLANATIONS OF ACTIVITIES

ANNEX 1.0

Activity 1.1

Observation: When the glass is placed over the burning candle, the flame gradually becomes dim and goes out. At the same time, the water level inside the glass rises slightly above the level in the dish.

Explanation: The candle goes out because it uses up the oxygen inside the glass. Since oxygen makes up about 21% of air, once it is depleted, the flame cannot continue burning. The rise in water level occurs because the used-up oxygen reduces the air pressure inside the glass, allowing water from the dish to be pushed in by the greater air pressure outside.

Activity 1.2

Observation: Learners will notice that water does not enter the glass fully.

Conclusion and explanation: This is because air inside the glass prevents water from filling it, showing that air occupies space.

Activity 1.3

Observation: If carbon dioxide is present, the limewater will turn milky or cloudy.

Explanation: This happens because CO_2 reacts with calcium hydroxide to form calcium carbonate ($CaCO_3$), which is insoluble and makes the solution appear cloudy.

Activity 1.4

Environmental impact of changes in the percentages of components of air.

Air component	% in air	Role	If increased	If decreased
Nitrogen (N_2)	78%	• Provides inert balance • Dilutes oxygen • Supports nitrogen fixation	• Further dilutes oxygen, affects respiration • Reduces combustion • Minor climate/ health impact	• Increases oxygen levels, fire risk • Disrupts the nitrogen cycle • Affects soil fertility
Oxygen (O_2)	21%	• Essential for respiration • Supports combustion	• Higher fire risk • Increased metabolism, oxidative stress • May help breathing temporarily	• Breathing difficulties, fatigue • Risk of death at <15% • Collapse of aerobic life
Carbon dioxide (CO_2)	0.04%	• Needed for photosynthesis, • Greenhouse gas	• Global warming • Ocean acidification • Disrupts ecosystems	• Reduced photosynthesis and plant growth • Global cooling
Argon (Ag)	0.93%	• Inert gas • Stabilises the atmosphere	No significant effect (inert)	No significant effect (inert)
Water vapour	0-4% (Variable)	• Affects climate • Part of the water cycle	• Increased rainfall and clouds • Traps heat (greenhouse effect) • Floods and extreme weather	• Dry conditions • Reduced plant growth • Drought risk
Ozone/Oxone (O_3)	Trace	• Absorbs UV rays • Protects life	• Ground-level ozone causes smog • Respiratory problems	• More UV exposure • Skin cancer, cataracts • Harm to plankton and crops

Activity 1.6

Observations

1. Vigorous bubbling when baking soda meets vinegar
2. Balloon inflates.
3. The flame is extinguished by the suspected CO_2.

Conclusion: Bubbling and inflation indicate the release of a gas (CO_2).

Activity 1.9

Observation: The glowing splint rekindles (light-up)

Conclusion: Oxygen support for burning

ANNEX 2.0

Activity 2.0

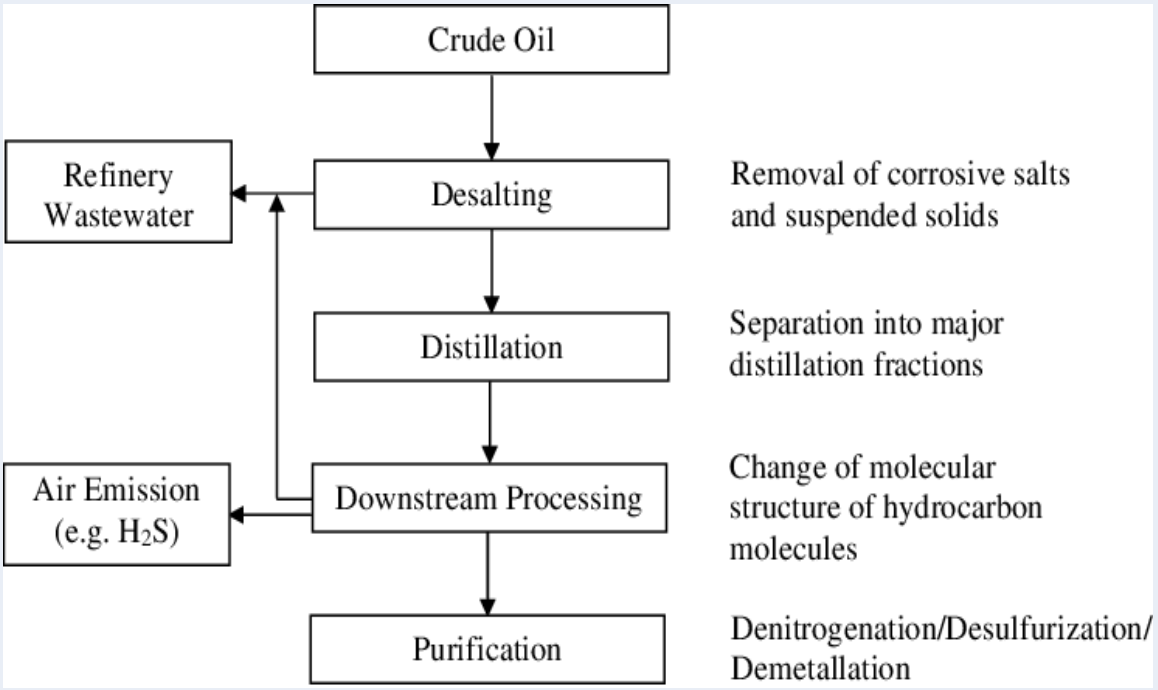
In the cold separation step, the lighter colours (such as green for petrol) separated and rose to the top first, while the heavier colours (such as red for heavy fuel oil) remained at the bottom. This showed that lighter fractions of oil separate more easily at low temperatures.

When the mixture was warmed in hot water, the layers mixed more at first, but as it settled, the heavier fractions (red and blue for heavy fuel oil and diesel) stayed at the bottom while the lighter ones (green and yellow for petrol and kerosene) moved upward. This showed that higher temperatures are needed to separate heavier fractions in refining.

In the density tower, the liquids settled in distinct layers: the coloured water (heaviest) stayed at the bottom, the oil mixture (diesel/kerosene) floated in the middle, and the light oil (petrol) rose to the top. This demonstrated that oil products separate based on density, just like in real fractional distillation.

Activity 2.2

Example flow chart



Flowchart of crude oil refinery processes.

ANNEX 3.0

Answer to the trial question on page xxxx

a. Role of the autonomic nervous system (ANS): The autonomic nervous system controls automatic body functions like heartbeat, breathing, and sweating. In Emmanuel's case, the ANS helped his body adjust to stress before the speech (by making his heart beat faster, his hands sweaty, and breathing quick) and then helped his body calm down afterwards (by slowing his heartbeat and breathing and making him feel relaxed).

b. Sympathetic and parasympathetic nervous systems:

i. The sympathetic nervous system prepared Emmanuel's body to face the stressful situation before the speech. It increased his heartbeat, made him breathe faster, and caused sweating. This is called the "fight or flight" response.

ii. The parasympathetic nervous system helped Emmanuel's body return to normal once he saw the audience smiling. It slowed his heartbeat, calmed his breathing, and made him feel relaxed. This is called the "rest and digest" response.

Note: *When the cup almost slipped from his hand, his nervous system reacted quickly through a reflex action, allowing him to grab the cup without thinking.*

Activity 3.7

Observation and Conclusion

Observation: The leg moves involuntarily after the tendon is tapped, demonstrating the reflex arc's function.

Conclusion: The knee-jerk response is a spinal reflex that bypasses the brain, highlighting the speed and efficiency of reflex actions.

ANNEX 4.0

Activity 4.7

Part of the body	Name of the joint found there
1. Between vertebrae	Cartilaginous joint (symphysis)
2. Wrist, ankle, or spine	Gliding/Planar joint
3. Shoulder or hip	Ball-and-socket joint
4. Between cranial bones	Fibrous joint (suture)
5. Knee or elbow	Hinge joint
6. In phalanges	Hinge joint
7. Between radius and ulna	Pivot joint
8. Neck (between C1 and C2 vertebrae) or elbow	Pivot joint

ANNEX 5.0

Activity 5.1

Observations

1. With all the holes aligned, the observer could see the source of light.

2. With one hole out of the line, the observer could not see the source of light again.

Conclusion: Light travels in a straight line.

Activity 5.2

Observation: The angle of incidence and angle of reflection must be equal for all angles of incidence chosen.

Conclusion: The laws of reflection of light hold true**.**

SOLUTION TO WORKED EXAMPLES

Worked example 5.1

According to the law of reflection:

Angle of incidence = Angle of reflection

So, angle of reflection=35°

Worked example 5.2

$\Theta r = \theta i = 40^\circ$

Total angle between the rays=$\theta i + \theta r = 40^\circ + 40^\circ = 80^\circ$

Worked example 5.4

By the New Cartesian convention,

Object distance, $u = -20$ cm

Focal length, $f = +10$ cm (convex mirror → positive)

Image distance, v = ?

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

$$\frac{1}{10} = \frac{1}{v} + \frac{1}{-20}$$

$$\frac{1}{v} = \frac{1}{10} + \frac{1}{20}$$

$$\frac{1}{v} = \frac{2+1}{20} + \frac{3}{20}$$

$v = +6.67$ cm

Result

- The image is formed 6.67 cm behind the mirror.
- It is virtual and erect (because v is positive).
- It is diminished in size.

Worked example 5.5

Refractive index = n = $\frac{c}{v}$

Where:

- n = refractive index
- c = speed of light in vacuum (3.00×10^8m/s)
- v = speed of light in the medium (2.25×10^8m/s)

Substituting the values, $\boldsymbol{n} = \frac{3.00 \times 10^8}{2.25 \times 10^8}$ $n = 1.33$

Worked example 5.7

Using Snell's law, $n_1 sin\theta_1 = n_2 sin\theta_2$

n_1=1.00, n_2 = 1.50, $\theta_1 = 30°$

Substituting values, $1.00 \times sin30° = 1.50 \times sin_2$

$0.5 = 1.50 \times sin\theta_2$

$sin\theta_2 = \frac{0.5}{1.50} = 0.333$

$\theta_2 = sin\theta^{-1}(0.333)$

$\theta_2 = 19.5°$

So, the light bends at approximately 19.5° in the glass.

Worked example 5.11

Real depth = Apparent depth × Refractive indes

Given, Apparent depth = 10 cm, refractive index = 1.33

Substituting values, Real depth = 10 × 1.33 = 13.3 cm

ANNEX 6.0

Activity 6.5

Observation: The number of marbles that move on the opposite end should equal the number that hits from one side, demonstrating momentum transfer.

SOLUTION TO WORKED EXAMPLES

Worked example 6.2

a. Momentum of the first car: 1.2 kg * 2 m/s = 2.4 kg m/s

b. Momentum of the second car: 1.4 kg * 0 m/s = 0 kg m/s

c. Total momentum before collision: 2.4 kg m/s + 0 kg m/s = 2.4 kg m/s

d. Their total momentum after the collision must be 2.4 kg m/s, since momentum is conserved.

Worked example 6.3

Initial momentum of both cars: (1000kg x 20m/s) + (1500kg x 10m/s) = 35000kgm/s

Since the cars stick together after a collision, they have a common velocity. Let this be v.

Final momentum: (1000kg + 1500kg) v = (2500kg) v.

By the principle of conservation of momentum, 35000kgm/s = (2500kg) v.

This implies v = 35000kgm/s / 2500kg = 14m/s.

When a super ball is dropped on the floor, it bounces back up, but not to the original height. Explain why this is an inelastic collision.

Explanation

a. **Collision:** The ball collides with the floor.

b. **Energy loss:** Some of the ball's kinetic energy is converted into heat, sound, and deformation of the ball and the floor. This is why it doesn't bounce back to the same height.

c. **Momentum is still conserved:** Even though kinetic energy is not conserved, the total momentum of the ball and the Earth is conserved. However, the Earth's mass is so large that its change in velocity is negligible.

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GLOSSARY

- Acetylcholine (ACh): A neurotransmitter released at nerve connections in both sympathetic and parasympathetic systems to transmit signals between neurons.
- Acid-Carbonate Reaction: A chemical reaction between an acid and a carbonate compound that produces carbon dioxide, water, and a salt.
- Action Potential: An electrical signal that travels along a neuron when the membrane potential reaches threshold (-55mV), involving rapid depolarisation and repolarisation.
- Adapter (Power Brick): A device that converts high-voltage alternating current (AC) from a wall outlet into the low-voltage direct current (DC) required by most electronic components.
- Adinkra Cloth: A Ghanaian fabric known for its stamped symbols, each with a deep philosophical meaning and proverb.
- Adire: A Yoruba resist-dyed textile from Nigeria, typically an indigo-dyed cotton cloth with striking patterns in blue and white.
- Afferent Nerves: Sensory nerves that carry information from the body's receptors to the central nervous system.
- Afferent Neurons: Sensory nerve cells that carry electrical signals from receptors toward the central nervous system for processing.
- Air: A mixture of invisible gases that surrounds the Earth and is needed for life.
- Air (Optics): The invisible mixture of gases surrounding the Earth, with a refractive index of about 1.0.
- Akwete Cloth: A hand-woven fabric from Nigeria, similar to Kente, known for its bold patterns and vibrant colours.
- Alkanes: A group of hydrocarbons found in crude oil, made of carbon and hydrogen atoms only.
- Angle of incidence: The angle between the incident ray and the normal at the point of incidence.
- Angle of incidence (dup): The angle between the incident ray and the normal at the point where light enters a medium.
- Angle of refraction: The angle between the refracted ray and the normal in the second medium.
- Angle of refraction (dup): The angle between the refracted ray and the normal in the new medium.
- Antagonistic Muscles: Pairs of muscles that work in opposition; when one contracts, the other relaxes; for example, biceps and triceps.
- Apparent depth: The perceived depth of an object submerged in a medium due to refraction, appearing shallower than its real depth.
- Apparent depth (dup): The perceived depth of an object when viewed through a transparent medium.

- Appendicular skeleton: The division of the skeleton consisting of the limbs (arms and legs) and their associated girdles (shoulder and pelvic girdles) that attach the limbs to the axial skeleton.
- Argon (Ar): A gas in the air that does not react easily; used in light bulbs and surgeries.
- Atlas (C1): The first cervical vertebra that lacks a centrum and has a ring-like structure with large articular facets that connect to the skull, allowing nodding movements of the head.
- Atmosphere: The blanket of gases that surrounds the Earth.
- Autonomic Nervous System: Controls involuntary functions like breathing, heart rate, and digestion.
- Autonomic Nervous System (ANS): The part of the peripheral nervous system that controls involuntary body functions like heartbeat, breathing, and digestion.
- Auxochromes: Functional groups in dyes that enhance their solubility and help them bind to fibres.
- Axial skeleton: The central framework of the skeleton, consisting of the skull, vertebral column, ribs, and sternum, that forms the main axis of the body.
- Axis (C2): The second cervical vertebra features a peg-like projection called the odontoid process that allows rotational movement of the head from side to side.
- Axon: The long projection of a neuron that conducts electrical impulses away from the cell body to other neurons or effector organs.
- Axon Terminal: The end portion of a neuron's axon that contains synaptic vesicles and releases neurotransmitters into the synaptic cleft.
- Ball and Socket Joint: A movable joint that allows movement in all directions; found in the shoulder and hip.
- Batik: A wax-resist dyeing technique where melted wax is applied to the fabric to block dye absorption.
- Battery: A component that stores chemical energy and converts it into electrical energy to power portable devices.
- Brain stem: Lower part of the brain that controls vital functions like breathing and heart rate.
- Buried: Covered under soil or rock deep underground.
- Canting (Tjanting): A pen-like tool with a copper reservoir and a fine spout used in batik to draw intricate lines with melted wax.
- Capillary Action: The process by which a liquid, such as a dye solution, spreads into the tiny spaces between fibres in a fabric.
- Carbon Dioxide (CO_2): A gas that plants use to make food and is also produced by breathing and burning.
- Cardiac Muscle: An involuntary, striated muscle found only in the heart; it contracts continuously without tiring.
- Cartilage: A tough, flexible connective tissue composed of living cells, carbohydrates, and protein fibres that acts as a shock absorber and reduces friction between bones at joints.

- Cartilage (Joints): A smooth, rubbery tissue that cushions bones at joints and reduces friction during movement.
- Catalyst: A substance that increases the rate of a chemical reaction without undergoing permanent chemical change itself (e.g., manganese (IV) oxide in H_2O_2 decomposition).
- Cellulose Fibres: The primary component of natural fabrics like cotton, which contain hydroxyl (-OH) groups that make them hydrophilic and receptive to dye molecules.
- Central Nervous System (CNS): The brain and spinal cord work together as the body's control centre.
- Centrum: The solid, cylindrical main body of a vertebra that bears weight, provides structural support, and serves as the point of articulation with adjacent vertebrae.
- Cerebellum: The "little brain" that controls balance, coordination, and movement.
- Cerebrospinal fluid: Clear liquid that cushions and protects the brain and spinal cord.
- Cerebrum: The largest part of the brain responsible for thinking, memory, and voluntary actions.
- Chitin: A tough, light, flexible carbohydrate material that forms the major component of arthropod exoskeletons, strengthened by deposits of hardened proteins and minerals.
- Chromophores: Chemical groups in dyes that are responsible for the colour by absorbing certain wavelengths of white light.
- Combustion: A chemical process in which a substance reacts with oxygen to release heat and light.
- Consumer Electronic Devices: Electrical or electronic gadgets intended for everyday use, primarily in private homes, which assist with communication, entertainment, and household chores.
- Contact Forces: Forces that occur when the source of the force is in direct physical contact with the object it's acting on. Examples include muscular force, tension, and friction.
- Cooking Fuel: A source of heat energy used for cooking food, such as gas from natural sources.
- Cranial Nerves: Twelve pairs of nerves that connect the brain directly to parts of the head and neck without going through the spinal cord.
- Critical angle: The minimum angle of incidence in a denser medium at which light is refracted along the boundary between two media.
- Crude Oil: Unprocessed oil taken from underground; it contains different useful chemicals.
- Decomposition: A chemical reaction where one compound breaks down into two or more simpler substances (e.g., H_2O_2 decomposing into water and oxygen).
- Dendrites: Branch-like extensions of a neuron that receive electrical signals from other neurons and transmit them to the cell body.
- Dense medium: A substance in which light travels more slowly due to a higher refractive index
- Density: The measure of mass per unit volume; carbon dioxide is denser than air.

- Depolarisation: The process where the inside of a neuron becomes less negative (more positive) due to sodium ions entering the cell during an action potential.
- Dry Ice: The solid form of carbon dioxide used to keep things very cold.
- Effector: A muscle or gland that responds to nerve impulses by producing movement or secretion as the final step in a reflex arc.
- Efferent Nerves: Motor nerves that carry commands from the central nervous system to muscles and glands.
- Efferent Neurons: Motor nerve cells that carry commands from the central nervous system to muscles and glands to produce responses.
- Elastic Collision: A collision in which the total kinetic energy and momentum of the system are conserved. This means the objects bounce off each other without any loss of energy to other forms.
- Electricity: A form of energy used to power lights, machines, and appliances, often made by burning fuel.
- Electrostatic Force: The force that exists between electrically charged objects or particles, where like charges repel and opposite charges attract.
- Endoskeleton: An internal support structure found in vertebrates, primarily composed of bones or cartilage, that provides a structural framework and protection for internal organs.
- Energy: The power used to do work or make things move, light up, or heat.
- Excitatory neurotransmitter: Chemical messengers that increase the likelihood of the postsynaptic neuron generating an action potential, such as glutamate and acetylcholine.
- Exocytosis: The process by which synaptic vesicles fuse with the presynaptic membrane to release neurotransmitters into the synaptic cleft.
- Exoskeleton: A hard, external covering made mainly of chitin that protects and supports the bodies of invertebrates, particularly arthropods, and must be shed during growth.
- Extension: The straightening of a joint; for example, when the triceps contract to straighten the arm.
- Extraction: The process of taking oil or gas out of the ground.
- Fertiliser: A substance added to soil to help plants grow, often containing nitrogen.
- Fertilisers: Substances added to soil to help crops grow better, often made using natural gas.
- Fibre optics: Technology that uses thin strands of glass or plastic to transmit light signals using total internal reflection.
- Fight-or-Flight Response: The body's automatic reaction to danger, controlled by the sympathetic nervous system, that prepares for immediate action.
- Flash Memory: A type of non-volatile storage used in devices such as USB drives, memory cards, and smartphones.
- Flexion: The bending of a joint; for example, when the biceps contract to bend the elbow.
- Fluid Friction (Drag): The force that opposes the motion of an object through a fluid (a liquid or gas).

- Force: A push or a pull that acts on an object and can cause it to start or stop moving, speed up, slow down, change direction, or change its shape.
- Fossil Fuels: Fuels like oil, coal, and natural gas are formed from dead plants and animals over millions of years.
- Friction: A contact force that opposes the relative motion or the tendency of such motion between two surfaces in contact.
- Fuel: A material that is burned or used to produce energy.
- GABA (Gamma-Aminobutyric Acid): The main inhibitory neurotransmitter in the brain that reduces neuronal activity and prevents overstimulation of the nervous system.
- Ganglion: A cluster of nerve cell bodies outside the central nervous system where nerve signals are relayed in the autonomic system.
- Glass: A transparent solid material with a refractive index of about 1.5, used in lenses and windows.
- Gliding Joint: A movable joint where bones slide over each other; found in the wrist and ankle.
- Gravitational Force: The force of attraction between any two objects with mass. On Earth, this is the force of gravity that pulls everything towards the planet's core.
- Greenhouse Effect: When certain gases trap heat in the atmosphere, warming the Earth to a temperature suitable for life.
- Grey matter: Brain tissue containing nerve cell bodies, dendrites and unmyelinated axons; appears grey in colour.
- Hard Disk Drive (HDD): A long-term storage device that is non-volatile, meaning it retains data even without power.
- Hardware Engineer: An innovator who designs and develops the physical components of electronic devices, such as circuit boards and processors.
- Helium (He): A very light gas used in balloons and cooling machines.
- Hinge Joint: A movable joint that allows movement in one direction only; found in the elbow and knee.
- Homeostasis: The body's ability to maintain stable internal conditions despite external changes.
- Hydrocarbons: Compounds made of hydrogen and carbon; found in oil and gas.
- Hydrogen Peroxide (H_2O_2): A pale blue liquid used as an oxidiser, bleach, and antiseptic; it decomposes to form oxygen and water.
- Hydrophobicity: The property of a substance, such as wax, that makes it water-repelling.
- Hydrostatic skeleton: A skeletal system found in soft-bodied invertebrates that relies on the pressure of internal fluid surrounded by muscles to maintain shape and enable movement.
- Hypothalamus: Brain region that controls body temperature, hunger, thirst, and sleep.
- Incident ray: The ray of light that strikes the boundary between two media.

- Indicator: A chemical that changes colour in response to a chemical change, used to test for acidity or alkalinity (e.g., litmus, phenolphthalein, methyl orange).
- Inelastic Collision: A collision where the total kinetic energy of the system is not conserved, though momentum is. Some kinetic energy is converted into other forms of energy, like heat and sound.
- Inhibitory Neurotransmitter: Chemical messengers that decrease the likelihood of the postsynaptic neuron firing an action potential, such as GABA.
- Interneuron: A relay neuron found only in the central nervous system that connects sensory neurons to motor neurons in reflex arcs.
- Involuntary Actions: Automatic body functions that happen without conscious control, such as heartbeat and breathing.
- Joint: A place where two or more bones meet; allows for movement or support.
- Kente: A traditional Ghanaian textile woven from silk and cotton strips in vibrant, complex geometric patterns.
- Kinetic Friction: The friction that acts on objects when they are in motion. It has two forms: sliding friction and rolling friction.
- Kuntunkuni: A characteristic rusty brown dye made from the bark of the *Bombax brevicuspe* tree, used in the production of Adinkra cloth.
- LASER: A device that produces a narrow, intense, and coherent beam of light through optical amplification by stimulated emission of radiation.
- Leaching: A scientific process where soluble organic compounds, like dye pigments, are extracted from plant material into a hot liquid like water.
- LED (Light Emitting Diode): A simple light used as an indicator, for example, to show that a device is on or a battery is charging.
- Less dense medium: A substance in which light travels faster due to a lower refractive index.
- Leuco-indigo: A water-soluble, yellowish-green form of indigo created through chemical reduction. It oxidises back to its insoluble blue form when exposed to air.
- Ligament: A flexible connective tissue that connects bone to bone at a joint and provides stability.
- Light: A form of energy that travels in waves and can move through a vacuum or a medium.
- Limewater: A solution of calcium hydroxide used to test for carbon dioxide; turns milky when CO_2 is bubbled through it.
- Magnetic Force: The force applied by magnets to magnetic materials or other magnets, which can be either attractive or repulsive.
- Manganese (IV) Oxide (MnO_2): A black powder that acts as a catalyst in the decomposition of hydrogen peroxide to produce oxygen.
- Medium: A substance through which light travels.
- Medium of incidence: The medium in which light travels before striking a boundary.
- Medium of refraction: The medium into which light passes and bends after crossing a boundary.

- Medulla Oblongata: Part of the brain stem that controls autonomic functions like breathing, heart rate, and blood pressure.
- Methane: The main gas in natural gas; it burns to give energy.
- Microcontroller/Processor: Often called the "brain" of a device; it is the control centre that executes software instructions and performs calculations, managing the device's overall operation.
- Mobile Device Repair Specialist: A technician who focuses specifically on fixing mobile devices, handling issues such as cracked screens, battery replacements, and water damage.
- Mordant: A substance, often a metal salt, that acts as a chemical bridge to help a dye bind permanently to a fibre, improving colourfastness.
- Motor Neuron: A nerve cell that transmits signals from the central nervous system to muscles and glands, enabling movement and bodily functions.
- Multipolar Neuron: A type of neuron characterised by one axon and multiple dendrites extending from the cell body, commonly found as motor neurons.
- Muscle Tissue: A type of body tissue made up of muscle fibres; it contracts and relaxes to produce movement.
- Myelin Sheath: A fatty white substance that wraps around axons to insulate them and speed up the transmission of nerve impulses.
- Natural Gas: A naturally occurring gas found underground, primarily composed of methane. It is used for cooking, heating, and generating electricity.
- Neural Arch: The bony arch that extends from the back of the vertebral centrum and, together with the centrum, encloses the neural canal that houses and protects the spinal cord.
- Neurotransmitters: Chemical messengers stored in synaptic vesicles that carry signals across synapses between neurons or from neurons to effector cells.
- Newton (N): The standard unit of force in the International System of Units (SI). It is defined as the force required to accelerate a one-kilogram mass at a rate of one meter per second squared (1 N=1 kg·m/s2).
- Nitrogen (N_2): The most common gas in the air; helps plants grow and is part of proteins.
- Nodes of Ranvier: Small gaps in the myelin sheath along an axon that facilitate the rapid transmission of electrical impulses.
- Non-Contact Forces: Forces that act on objects from a distance without physical contact.
- Norepinephrine: The main neurotransmitter released by sympathetic nerve endings that causes stress responses in target organs.
- Normal: An imaginary line drawn perpendicular to the surface at the point where the incident ray meets the boundary.
- Normal (dup): An imaginary line drawn at right angles to the surface where the light ray meets the medium.

- Ossification: The process of bone formation involving the development of bone tissue and deposition of minerals like calcium phosphate into a tissue matrix to form hardened bone.
- Osteocytes: Living bone cells embedded within the bone matrix that maintain bone tissue and facilitate the exchange of nutrients and waste products through small channels.
- Oxygen (O_2): A gas needed for breathing and burning. It constitutes 21% of the air.
- Parasympathetic Nervous System: The division of the autonomic nervous system that promotes "rest-and-digest" activities and energy conservation.
- Pentadactyl Limb: The basic five-digit (finger/toe) structural plan found in vertebrate forelimbs and hindlimbs, consisting of similar bone arrangements despite different functions.
- Perfectly Inelastic Collision: A specific type of inelastic collision where the objects stick together after impact and move with a common final velocity.
- Peripheral Nervous System (PNS): All nerves outside the brain and spinal cord that connect the central nervous system to the body.
- Photosynthesis: A biological process by which green plants convert carbon dioxide and water into glucose and oxygen using sunlight.
- Physical Properties: Observable characteristics of a substance that do not change its composition (e.g., colour, odour, density, solubility).
- Pivot Joint: A movable joint that allows rotational movement; found in the neck between the atlas and axis vertebrae.
- Pollution: Harm caused to the environment by dirty or harmful substances like smoke or oil spills.
- Postsynaptic Neuron: The receiving neuron in synaptic transmission that has receptors for neurotransmitters on its membrane surface.
- Preparation: The method or process used to produce a chemical substance in the laboratory.
- Pressure: A force that pushes on something; deep underground, pressure helps form fossil fuels. It is defined as the force applied perpendicular to a surface per unit area.
- Presynaptic Neuron: The sending neuron in synaptic transmission that releases neurotransmitters from its axon terminal into the synaptic cleft.
- Printed Circuit Board (PCB): A rigid board with a network of copper traces that physically support and electrically connect all other components, acting as the skeleton of the device.
- RAM (Random Access Memory): The device's short-term, volatile memory used to store data that the processor is actively using. Its contents are lost when the device is turned off.
- Ray: A straight-line path showing the direction in which light energy travels.
- Real depth: The actual vertical distance from the surface of a medium to a submerged object.
- Receptor: A specialised structure that detects stimuli from the environment and converts them into electrical signals for the nervous system.

- Reflex Action: A quick, automatic, and involuntary response to a stimulus that occurs without conscious thought or decision-making.
- Reflex Arc: The complete neural pathway that a nerve impulse follows during a reflex action, from stimulus detection to response execution.
- Refracted ray: The ray of light that has changed direction upon passing into a new medium.
- Refraction: The bending of light as it passes from one medium to another with a different optical density.
- Refraction (dup): The bending of light as it passes from one medium to another with a different refractive index.
- Refractive index: A measure of how much the speed of light is reduced when passing through a medium, calculated as the ratio of the speed of light in a vacuum to the speed of light in the medium.
- Refractive index (dup): A measure of how much a medium slows down light compared to its speed in a vacuum.
- Repolarisation: The process by which the neuron returns to its resting potential after depolarisation, primarily through potassium ions leaving the cell.
- Resist Method: A technique used in textile dyeing where specific areas of a fabric are physically blocked from absorbing dye.
- Respiration: A biological process by which living organisms convert glucose and oxygen into energy.
- Rest-and-Digest Response: The body's calm state is promoted by the parasympathetic system that supports digestion and recovery.
- Resting potential: The stable electrical charge (-70mV) maintained by a neuron when it is not transmitting a signal, with more sodium outside and potassium inside.
- Reuptake: The process by which neurotransmitters are taken back into the presynaptic neuron after being released, allowing for recycling and signal termination.
- Saltatory conduction: The rapid transmission of nerve impulses in myelinated neurons, where the signal jumps between nodes of Ranvier, increasing transmission speed.
- Sensor: An input device that detects changes in the environment, such as a touchscreen, accelerometer, or microphone, and converts them into electrical signals for the microcontroller to understand.
- Sensory Neuron: A nerve cell that detects stimuli from the environment and converts them into electrical signals transmitted to the central nervous system.
- Skeletal Muscle: A voluntary, striated muscle attached to bones by tendons; responsible for body movement.
- Smooth Muscle: An involuntary, non-striated muscle found in internal organs; it works slowly and does not tire easily.
- Snell's law: A law stating that the ratio of the sine of the angle of incidence to the sine of the angle of refraction equals the ratio of the refractive indices of the two media.
- Snell's law (dup): A formula that relates the angles of incidence and refraction to the refractive indices of two media.

- Solid-State Drive (SSD): A non-volatile, long-term storage device for an operating system, applications, and user files.
- Solubility: The ability of a substance to dissolve in water; carbon dioxide is sparingly soluble.
- Somatic Nervous System: The part of the peripheral nervous system that controls voluntary muscle movements and conscious sensations.
- Speaker: A component that converts electrical signals back into sound waves, allowing you to hear audio from a device.
- Speed of light: The rate at which light travels, fastest in a vacuum and slower in denser media.
- Sympathetic Nervous System: The division of the autonomic nervous system that activates the body's stress response and "fight-or-flight" reactions.
- Synaptic cleft: The small gap (20-40 nanometres) between the presynaptic and postsynaptic neurons where neurotransmitters travel to transmit signals.
- Tendon: A strong, fibrous and inelastic tissue that connects muscle to bone; helps transmit force during movement.
- Trace Gases: Gases found in very small amounts in the air but still important, like helium and ozone.
- Transistor: An electronic component that regulates current or voltage flow and acts as a switch or gate for electronic signals.
- Upthrust (Buoyant Force): A vertical upward force that a fluid (a liquid or gas) applies to an object placed in it, helping it to float.
- Vertebrae: Individual bones that make up the vertebral column, joined end to end to form a flexible, protective tube for the spinal cord while providing support and muscle attachment points.
- Viscosity: A measure of a fluid's resistance to flow. Thicker, more viscous fluids flow slowly, while thinner ones flow quickly.
- Water Vapour: Water in gas form in the air, important for weather and temperature.
- White matter: Brain tissue containing nerve fibres; appears white due to myelin coating.

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